sciendo

Studia Geotechnica et Mechanica, 2018; 40(1): 21–29

Research Article **Open Access**

Anu James*, Babu Kurian

Comparison of Analysis Specifications and Practices for Diaphragm Wall Retaining System

https://doi.org/10.2478/sgem-2018-0004
received December 9, 2017; accepted March 23, 2018.

Abstract: Diaphragm walls are deep embedded earth retaining structures. They also act as a part of the foundation. Geotechnical codes of practice from various countries provide procedures for the analysis of deep foundations. Not many standards are available that directly regulate the analysis of diaphragm walls. This paper compares the analysis of diaphragm walls performed using the foundation codes of different countries. Codes including EN 1997-1, BS 8002, BS 8004, BS EN 1538, AASHTO LRFD Bridge Design Specifications, AS 4678, AS 5100.3, Canadian Foundation Engineering Manual, CAN/CSA S6, IS 9556 and IS 4651 are chosen for the study. Numerical studies and calculations are done using the finite element software Plaxis 2d. Comparative study is performed based on the values of displacements and the forces developed. Study also evaluates the effect of differences in partial safety factors. The outcome of research emphasises the need for development of comprehensive analysis procedures.

Keywords: Diaphragm wall; numerical analysis; codes; partial factor; total resistance factor.

1 Introduction

Diaphragm walls or structural slurry walls are embedded earth retaining systems. These are gaining popularity as support for deep excavations and are one among the best solutions for space constraints in urban areas. The construction of diaphragm wall panels is done using the slurry trench technique. Greater care should be given to the excavation process as the failure of diaphragm walls during or after the construction will cause heavy causalities. Collapse of diaphragm walls or defects in support systems may affect the stability of adjacent structures. Hence, reliable understanding of the loads and stresses developing on the system is essential. For this, perfect structural analysis methods considering special requirements of diaphragm walls should be adopted.

The available literature includes comparative studies of different codes and standards. Fellenius [17] compared the provisions included in various codes for pile foundations and observed that there is lack of consistency regarding the determination of real pile capacity. Bakhoum et al. [3] studied the specifications concerning the structural actions and resistances in different building codes. They compared design building codes of USA, Europe and Egypt. Provisions regarding loads and resistances of sections carrying flexural and compressive axial loads were assessed. They concluded that the Egyptian code gives values that are same as the European code except for office buildings. It is also found that the Egyptian standards demand larger section dimensions and higher reinforcement ratios. Brown et al. [8] compared the design practices of bored piles and drilled shafts in the European and North American codes. Issues identified include concerns regarding reinforcement, construction technique and concrete mix design. The study describes recommendations and guidelines from the assessed codes. A comparison of design specifications in ACI 318 and BS 8110 was performed by Tabsh. [25] The work focused on flexural, shear and axial compressive capacity of various members. The study shows that the variations are not much pronounced in the areas of flexure but are severe in cases of shear. Lewandowska and Czajewska [20] analysed the diaphragm walls according to the provisions of Eurocode 7 and Polish code. The study compared the current methods used in Poland and the new methods that are about to be introduced when Poland adopt the European standards. The study recommends the implementation of design approach 2 from the Eurocode 7 due to its economic values and comparable safety levels. Wijaya and Taiebat [26] studied the effects of factors

---

***Corresponding author: Anu James,** Department of Civil Engineering, Mar Athanasius College of Engineering, Kerala, India, 686666, E-mail: anumercyjames@gmail.com
Babu Kurian: Department of Civil Engineering, Mar Athanasius College of Engineering, Kerala, India, 686666

of safety provided in AS 4678. Khabbaz and Aung [19] compared the global and partial safety factors detailed in AS 4678 and concluded that the partial factor method has a more conservative approach than the overall factor method. Simpson [21] studied the effects of partial factors of safety in geotechnical analysis. The paper focused on the optimal area of application of partial safety factors. Fenton et al. [18] describes the development of limit states in the Canadian geotechnical codes and the recent advances in geotechnics.

This paper compares the analysis of diaphragm walls performed using the specifications given in various codes of foundations and earth retaining structures. In the absence of standards that directly govern the special requirements of diaphragm walls, they must be analysed by the guidelines stated in these codes. Codes of different countries provide different procedures, factors and data for the analysis of retaining structures and deep foundations. Hence, it is essential to check the specifications given and their applicability for the analysis of diaphragm walls. The codes considered for the study include AASHTO LRFD Bridge Design Specifications, AS 4678, AS 5100.3, AS/NZS1170.1, BS 8002, BS 8004, BS EN 1538, Canadian foundation engineering manual, CAN/*CSA S6*, EN 1997-1, EN 1997-2, IS 9556, IS 4651 Part 2 and 4. Many of these codes follow limit state methods, while some follow working stress conditions. Most of the geotechnical codes insists factoring of loads and resistances. This is done either by partial resistance factor method or total resistance factor method. In the partial factors method, properties of ground are individually factored. This is based on the concept that the uncertainty affecting each parameter will be different. In the total resistance factor method, final values of ground properties are factored.

2 Numerical Studies and Results

A numerical study is performed using the finite element-based software Plaxis 2d. Braced excavation supported by a reinforced concrete diaphragm wall [20] as shown in Fig. 1 is considered. The excavation depth is 6 m and the embedded depth is 4 m. Wall is supported by a single strut located at 1.5 m below ground level. Ground water level is at a depth of 4 m. Permanent (10 kN/m^2) and variable (50 kN/m^2) overburden pressures are acting on the backfill. The material characteristics of the retained ground are as follows: Modulus of elasticity E_s = 30 N/mm^2, Poisson's Ratio = 0.3, effective angle of internal friction $\phi = 27^0$, cohesion C = 10 kN/m^2, saturated unit weight = 20 kN/m^2 and unsaturated unit weight = 19 kN/m^2. The material properties of the wall are fixed as: Modulus of elasticity, E_w = 30 N/mm^2, Poisson's Ratio = 0.19, thickness = 800 mm. Finite element software Plaxis 2d is used for the analysis. Maximum values of lateral deflection, bending moment and shear force occurring on the wall and axial force developed on the strut are calculated. The similarities and variations in the results are evaluated.

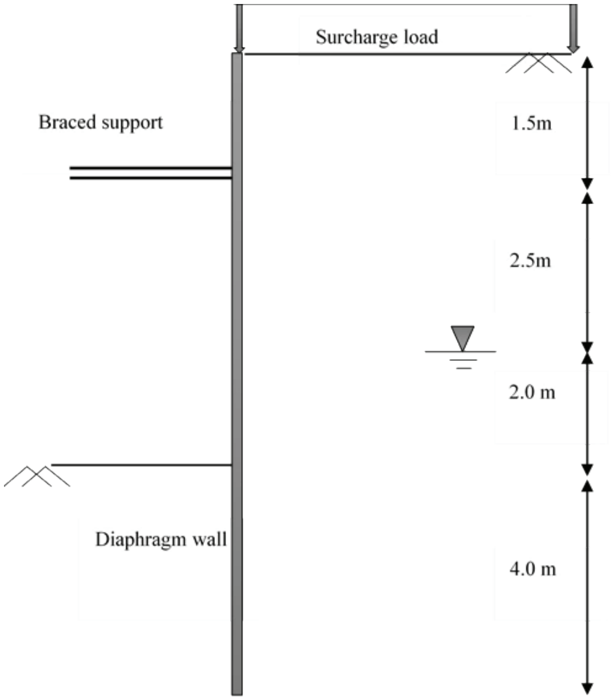

Figure 1: Strutted diaphragm wall.

2.1 Methodology

Calculations are done under plain strain conditions. Diaphragm wall sections are simulated using elastic plate element defined by normal stiffness, bending stiffness and Poisson's ratio. Soil masses are modelled as elastic plastic material with Mohr-Coulomb failure criterion, while struts are modelled by the fixed end anchor element facility in Plaxis. The analysis includes the following construction stages.

1. Activation of Diaphragm walls and loads
2. Excavation up to a depth below proposed strut location
3. Installation of strut
4. Dewatering up to the level of excavation
5. Excavation up to final depth

Table 1: Partial factors of safety applied on loads.

CODE	Standard/ limit state case	Loads				Water Pressure	Active E.P.	Passive E.P.
		Permanent		Variable				
		Favourable	Unfavourable	Favourable	Unfavourable			
Europe	D1 A	1	1.35	-	1.5	1	-	1
	D1 B	1	1	-	1.3	1	-	1
	D2	1	1.35	-	1.5	1	-	1.4
	D3	1	1.35	-	1.5	1	-	1
Australia	Strength	1.5		-		1	1.25	0.8
	Stability	1.5		-		1	1.25	0.8
	Serviceability	0.7		-		1	1	1
USA	AASHTO	1.5–0.7		1.75		1	1.35–1	0.75
India	Serviceability	1		-		1	1	1
	Collapse	1.5		-		1	1.2	1.2
Britain	D1 A	1	1.35	-	1.5	1	-	1
	D1 B	1	1	-	1.3	1	-	1
Canada	CHBDC	-	-	-	-	1.1-0.9	1.25–0.8	0.75

Table 2: Partial factors of safety applied on material parameters.

CODE	Standard/ limit state case	Cohesion (C)	Angle of internal friction (φ)	Wall specific weight (w)
Europe	D1 A	1	1	1
	D1 B	1.25	1.25	1
	D2	1	1	1
	D3	1.25	1.25	1
Australia	Strength	0.7	0.85	1.25
	Stability	-	-	0.8
	Serviceability	0.85	1	1
USA	AASHTO	-	-	1.25–0.9
India	Serviceability	-	-	1
	Collapse	-	-	1.5
Britain	D1 A	1	1	1
	D1 B	1.25	1.25	1
Canada	CHBDC	-	-	1.2–0.9

A significant issue regarding excavation modelling is the way in which partial factors are applied. Partial factors should be applied on material properties and loads. Coefficients to be imposed on loads and material properties according to the various codes are listed in Table 1 and Table 2.

Factored values of loads, resistances and material properties should be used for calculations and modelling. For the modification of material properties, factored values can be directly entered into the material sets of Mohr-Coulomb model. The material parameters on which partial coefficients are applied are cohesion, angle of internal friction and wall specific weight (unit weight of wall material multiplied by wall thickness). Table 3 gives the ultimate values included in the material set.

Safety factors on loads and resistances need to be carefully applied since they should take into account the load variations during the excavation process. To incorporate the load variations, factoring must be done on such parameters that the factored loads at each construction stage will be revised automatically. Here, the partial coefficients are applied on saturated and unsaturated unit weights of soil (γ_{sat}, γ_{unsat}), uniformly distributed load representing surcharge loads and unit weight of ground water (γ_{gw}). The modified values of these parameters, after the application of partial factors, are entered into the material sets of input file. Separate soil profiles are created in the material set for active and passive soil mass. The reduction factors for resistances are applied on passive soil profile set and the corresponding load increment factors are entered into the active soil profile set. In this manner, factored loads and resistances can be calculated accurately for every construction stage. The final factored values are given in Table 4.

Table 3: Factored values of material properties.

CODE	Standard/ limit state case	C (kN/m²)	ϕ (deg.)	w (kN/m²)
Europe	D1 A	10	27	20
	D1 B	8	22.17	20
	D2	10	27	20
	D3	8	22.17	20
Australia	Strength	7	23.42	25
	Stability	10	27	16
	Serviceability	8.5	27	20
USA	AASHTO	10	27	25
India	Serviceability	10	27	20
	Collapse	10	27	30
Britain	D1 A	10	27	20
	D1 B	8	22.17	20
Canada	CHBDC	10	27	24

2.2 Euro codes

European standards of foundations and earth and retaining structures used for the study are EN 1997-1 Geotechnical design - Part 1: General rules [15] and EN 1997–2 Geotechnical design- part 2: Ground investigation and testing [16]. Eurocode 7 offers three design approaches namely DA 1, DA 2 and DA 3. They define the way in which partial safety factors are distributed. The design values (S_d) [15] should be calculated as stated in Eq. (1):

$$S_d = S_k / \gamma_M \tag{1}$$

where, S_k is the characteristic value of material properties and γ_M is the corresponding partial safety factor. Partial factors are provided for actions/effect of actions (A1, A2), material properties (M1, M2) and ground resistances (R1, R2, R3).

The design approaches are defined as:

i. DA1- A: A1 + M1+ R1
ii. DA1- B: A2 + M2 + R1
iii. DA2: A1 + M1 + R2
iv. DA3: A1 + M2 + R3

Partial coefficients applicable for the analysis are given in Table 1 and Table 2. The third design approach is omitted from calculations due to its similarity with DA1.

Table 4: Factored values applied for calculating loads and resistances.

CODE	Standard/ limit state case	Surcharge (kN/m²)		γ_{gw} (kN/m²)	Active E.P (kN/m²)		Passive E.P (kN/m²)	
		Permanent	Variable		γ_{sat}	γ_{usat}	γ_{sat}	γ_{usat}
Europe	D1 A	13.5	75	10	20	19	20	19
	D1 B	10	65	10	20	19	20	19
	D2	13.5	75	10	20	19	14.29	13.57
	D3	13.5	75	10	20	19	20	19
Australia	Strength	15	50	10	25	23.75	16	15.2
	Stability	15	50	10	25	23.75	16	15.2
	Serviceability	7	50	10	20	19	20	19
USA	AASHTO	15	87.5	10	27	25.65	15	14.25
India	Serviceability	10	50	10	20	19	20	19
	Collapse	15	50	10	24	22.8	24	22.8
Britain	D1 A	13.5	75	10	20	19	20	19
	D1 B	10	65	10	20	19	20	19

Table 5: Results of analysis with EC7.

Case	H_{max} (mm)	$B.M_{max}$ (kNm)	$S.F_{max}$ (kN)	T(kN)
D1 A	4.41	226.41	140.58	151.2
D1 B	11.52	297.06	180.1	231.1
D2	8.86	163.83	201.2	146.2

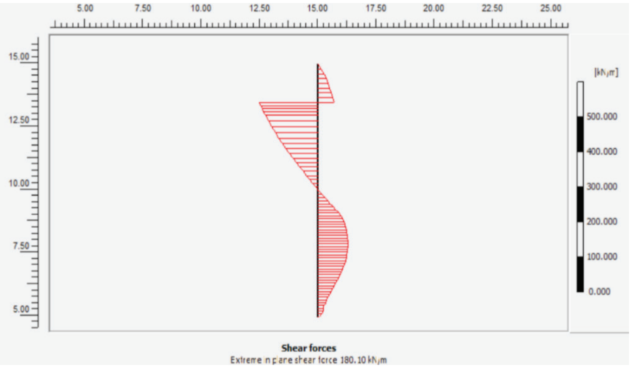

Figure 2: Maximum shear force developed on wall panel as per EC 7(D1 B).

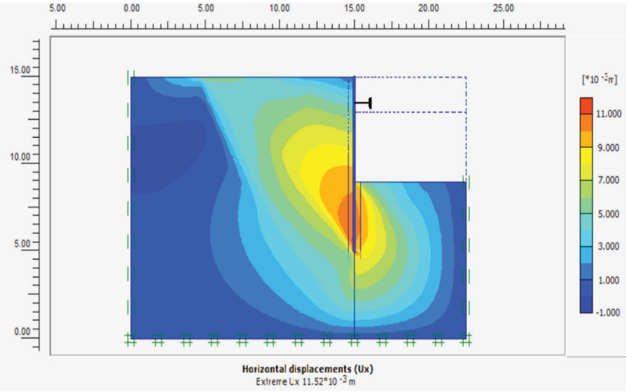

Figure 3: Maximum lateral deflection of diaphragm wall panel as per EC 7(D1 B).

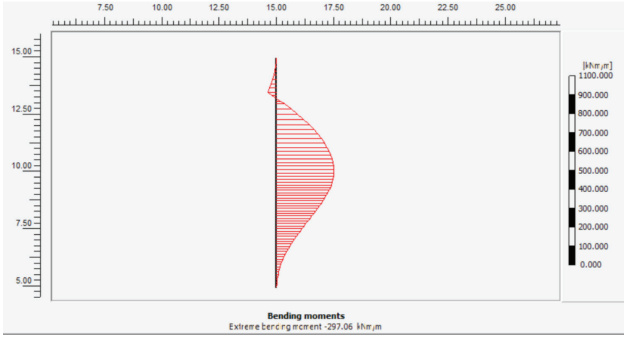

Figure 4: Maximum bending moment developed on wall panel as per EC 7(D1 B).

The maximum values of lateral deflection (H_{max}), bending moment ($B.M_{max}$) and shear force ($S.F_{max}$) acting on the wall and the axial force developed on the strut (T) are given in Table 5. Examples of results are demonstrated in Figs. 2–4.

2.3 Australian standards

Australian standards chosen for the analysis of diaphragm walls are AS 4678: Earth retaining structures [22], AS 1170.1 Part 1: Dead and live loads and load combinations [23] and AS 5100.3: Bridge Design-Part 3: Foundations and soil supporting structures [24]. Condition specified in Eq. (2) must be satisfied for all load combinations [22,23].

$$R \geq S \tag{2}$$

where R is the factored design resistance and S is the factored design action. Partial coefficients for design are described in AS 4678 [22]. These factors are given in three groups; reduction factors φ_R, uncertainty factors φ_U, and structure classification factors φ_N. Safety factors on material strength are applied on cohesion (c) and tangent of angle of internal friction (φ) as stated in Eq. (3) and Eq. (4).

$$c^{*} = \Phi_{uc}\, c \tag{3}$$

$$\varphi^{*} = tan^{-1}\,(\Phi_{u\varphi}\,(tan\varphi)) \tag{4}$$

where, φ_{uc} and $\varphi_{u\varphi}$ represent the reduction factors for c and φ respectively. The code recommends a minimum surcharge load of 5 kPa. The partial coefficients to be applied according to the Australian standards are listed in Table 1 and Table 2. The factored values entered into the model are given in Table 3 and Table 4. The results of analysis are given in Table 6.

The partial factors applied as per the limit states of strength and stability resulted in excavation failure indicating the need for introduction of extra support. The values shown merely represent those obtained from the analysis.

2.4 Indian standards

The Indian codes of practice referred for the study are IS 9556: Code of practice for design and construction of diaphragm walls [9], IS 4651-Part 4: Planning and design of port and harbours-Earth pressures [10] and IS 4651-Part 2: Planning and design of port and harbours

Table 6: Results of analysis using Australian codes.

Case/ Limit state	H_{max} (mm)	$B.M_{max}$ (kNm)	$S.F_{max}$ (kN)	T (kN)
Strength	31.5	334	220	331
Stability	23.5	315	79.57	229
Serviceability	8.18	195.16	127.43	164.4

– General design considerations [11]. IS 9556 illustrates the requirements of slurry wall construction procedures, material characteristics, equipment and accessories. IS 4651 (Part 2) explains the methods for estimating lateral loads and IS 4651 (Part 4) gives the partial coefficients to be applied on lateral pressures. The design values of material strengths (M_d) and loads (F_d) as per Indian standards [11] are given in Eq. (5) and Eq. (6).

$$M_d = \frac{F_m}{\gamma_m} \tag{5}$$

$$F_d = F_l \gamma_f \tag{6}$$

where F_m and F_l are the characteristic strengths of materials and loads. γ_m and γ_f represent corresponding safety factors. The partial coefficients for limit states of serviceability and collapse are given in Table 1 and Table 2. The final values are given in Table 3 and Table 4. Table 7 shows the results of analysis according to the Indian standards.

2.5 American standards

The American standard used for the analysis is AASHTO LRFD bridge design specifications [1,2]. The code implements the use of limit states on geotechnical requirements and hence can be applied for foundation design [17]. For the calculation of geotechnical parameters, LRFD (Load and Resistance Factor Design) method is followed. AASHTO specifications assign safety factors on actions and resistances. For each limit state, an overall factor is applied on the ground resistances calculated from unfactored parameters. The final factored load as per AASHTO should be computed using Eq. (7):

$$Q = \Sigma n_i \gamma_i Q_i \tag{7}$$

where n_i, γ_i and Q_i represent load modifier, load factor and load effect respectively. Load modifier is a factor related to ductility, redundancy and operational classification [2].

Table 7: Results of analysis with Indian codes.

Case/Limit state	H_{max} (mm)	$B.M_{max}$ (kNm)	$S.F_{max}$ (kN)	T (kN)
Serviceability	8.13	188.28	112.67	132.3
Collapse	10.68	241.4	152.11	185.8

Table 8: Results of analysis with American code.

Case	H_{max} (mm)	$B.M_{max}$ (kNm)	$S.F_{max}$ (kN)	T (kN)
AASHTO	13.32	276.15	152.92	176.1

Load factors are multipliers assigned to the load effects. The load factors applicable for the analysis of diaphragm walls are listed in Table 1 and Table 2. The results are shown in Table 8.

2.6 Canadian standards

The standards that can be used for the analysis of diaphragm walls are the Canadian Foundation Engineering Manual [12] and the Canadian Highway Bridge Design Code (CHBDC) [13,14]. Canadian codes apply the total resistance factor approach. In this method, the parameters are not individually factored. According to CHBDC, the designs of embedded walls are to be regulated by the overall stability of the wall, overturning and horizontal resistances. The design values [12] are given by Eq. (8):

$$\varphi R_n \geq \Sigma \alpha_i S_{ni} \tag{8}$$

where φR_n represents factored geotechnical resistance. R_n is the ultimate ground resistance and φ is the geotechnical resistance factor. $\Sigma \alpha_i S_{ni}$ denotes the total factored load with α_i being the load factor. The load factors and resistance factors can be obtained from standards like the National building code of Canada and Canadian highway bridge design code. The numerical values of partial factors to be applied and their factored values are given in Tables 1–4. Table 9 shows the results of analysis.

2.7 British standards

The British standards considered for the analysis are BS 8002: Earth retaining structures [6], BS 8004: Foundations [7], BS NA EN 1997-1: British National Annex to Eurocode

Table 9: Results of analysis with Canadian codes.

Case	H_{max} (mm)	$B.M_{max}$ (kNm)	$S.F_{max}$ (kN)	T (kN)
Canada	14.98	232.3	142.31	179.4

Table 10: Results of analysis with British standards.

Case	H_{max} (mm)	$B.M_{max}$ (kNm)	$S.F_{max}$ (kN)	T(kN)
D1 A	4.41	226.41	140.58	151.2
D1 B	11.52	297	180.1	231.1

[5] and BS EN 1538: Execution of special geotechnical works – Diaphragm walls [4]. BS EN 1538 give guidance for the design, construction and execution of diaphragm walls. The earlier versions of BS 8002 and BS 8004 were temporarily withdrawn in 2010 and deemed by Eurocodes. Partial safety coefficients are provided in the British National Annex to Eurocode. The recent codes provide guidance for implementing the conditions of Eurocode 7. National Annex adopts DA 1 for the analysis of earth retaining structures. The partial factors and their ultimate values are given in Tables 1–4. These are same as that of the first design approach in Eurocode 7. The results are shown in Table 10.

3 Comparative Study

Analysis of a braced diaphragm wall was performed using the specifications given in various codes and standards for earth retaining structures. The codes considered for the study include EN 1997-1, BS 8002, BS 8004, BS EN 1538, AASHTO LRFD Bridge Design Specifications, AS 4678, AS 5100.3, Canadian foundation engineering manual, CAN/CSA S6, IS 9556 and IS 4651. The maximum values of lateral displacement, bending moment and shear force occurring on the wall and the axial force developed on the strut are computed for each standard. The similarities and variations in the results are evaluated. Fig. 5 and Fig. 6 shows a graphical representation of the results. The relative percentage variation of every parameter normalised with the corresponding minimum is presented in Table 11.

The variations in results calculated by each code with respect to others can be observed from Figs. 7–9. It is apparent that among the three design approaches of Euro code 7, combination 2 of the first design approach give maximum values. Maximum lateral displacements are obtained for calculations using the American and Canadian standards.

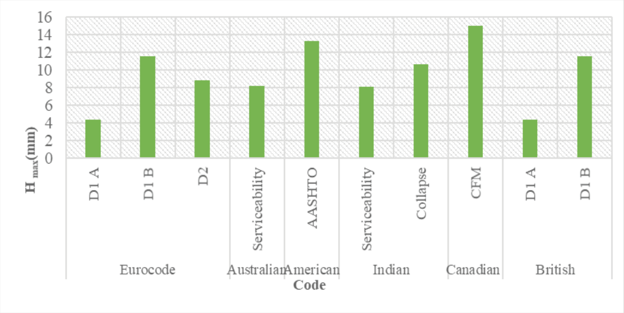

Figure 5: Representation of variations in H_{max}.

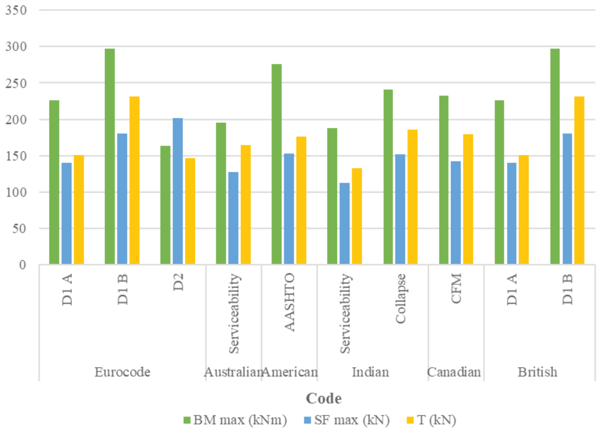

Figure 6: Representation of variations in $B.M_{max}$, $S.F_{max}$ and T.

Table 11: Relative percentage increase of parameters.

Case	% variation in H	% variation in BM $_{max}$	% variation in SF $_{max}$	% variation in Strut Force (T)
EC- D1 A	0.00	38.20	24.55	14.13
EC- D1 B	161.22	81.29	59.32	74.68
EC- D2	100.91	0.00	77.88	10.51
AUS	85.49	19.12	12.98	24.26
USA	202.04	68.56	35.41	33.11
IND-S	84.35	14.92	0.00	0.00
IND-C	142.18	47.35	34.70	40.44
CAN	239.68	41.79	26.08	35.60

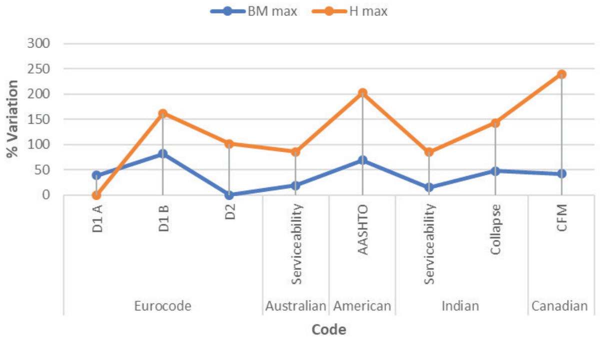

Figure 7: Comparison of percentage variation in B.M$_{max}$ and H$_{max}$.

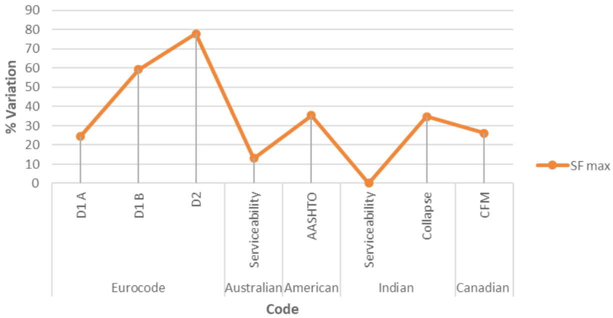

Figure 8: Comparison of percentage variation in SF$_{max}$.

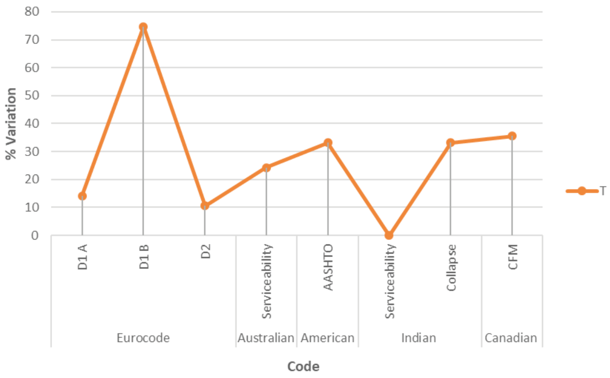

Fig. 9 Comparison of percentage variation in T

4 Conclusions

Following are the conclusions drawn from the analysis of diaphragm wall using various geotechnical codes.

1. Codes of practice for foundations and earth retaining structures from six countries are considered for the study.
2. The codes considered follow different limit state conditions. The American and Canadian codes follow the total resistance factor approach. The European and British codes follow the partial factors method and the Indian foundation codes are based on the working stress methods. This led to factoring of different parameters.
3. Even though the values of partial factors for each parameter show variations, they fall in a similar range.
4. Minimum lateral deflection is given by Design Approach 1 of Eurocode 7.
5. Maximum lateral deflection and bending moment are obtained from the analysis done according to the American and Canadian codes, that is, the codes that apply total resistance factor approach. The relative percentage increase with respect to minimum is more than 200%.
6. Higher values of bending moments are given by the first design approach of Eurocode, American and Canadian codes.
7. Similar values are obtained for lateral deflection, bending moment and strut force when DA 2 of Eurocode 7, Australian code and serviceability limit states of Indian codes are applied. Their variations lie within 20%.

From the comparative studies, it is felt that detailed investigations are required to formulate a comprehensive analysis procedure for diaphragm walls considering all the influencing parameters.

References

[1] American Association of State Highway and Transportation Officials. (2012). AASHTO LRFD Bridge Design Specifications. Washington DC.

[2] American Association of State Highway and Transportation Officials. (2016). AASHTO LRFD Bridge Design Specifications. Washington DC.

[3] Bakhoum, M.M., Mourad, S.A. & Hassan, M.M. (2016). Comparison of actions and resistances in different building design codes. *J. Adv. Res.* 7(5), 757–767. DOI:10.1016/j.jare.2015.11.001.

[4] British Standards Institution. (2000). British standard: Execution of special geotechnical works - Diaphragm walls. BS EN 1538:2000. London.

[5] British Standards Institution. (2004). UK National Annex to Eurocode 7 Geotechnical design, General rules. BS NA EN 1997-1:2004. London.

[6] British Standards Institution. (2015). British standard: Code of practice for earth retaining structures. BS 8002:2015. London.

[7] British Standards Institution. (2015). British standard: Code of practice for foundations. BS 8004:2015. London.

[8] Brown, D., Wulleman, T. & Bottiau, M. (2016). A comparison of design practice of bored piles/drilled shafts between Europe

and North America. *The Journal of the Deep Foundations Institute*. 10(2), 54-63. DOI:10.1080/19375247.2016.1254375

[9] Bureau of Indian Standards. (1980). Indian standard: Code of practice for design and construction of diaphragm walls. IS 9556:1980(R2003). New Delhi.

[10] Bureau of Indian Standards. (1989). Indian standard: Code of practice for planning and design of ports and harbours-Part 2 Earth Pressures. IS 4651 (Part 2):1989. New Delhi.

[11] Bureau of Indian Standards. (2014). Indian standard: Code of practice for planning and design of ports and harbours-General design considerations. IS 4651 (Part 4). New Delhi.

[12] Canadian Geotechnical Society. (2006). Canadian Foundation Engineering Manual. 4th edition. Canada.

[13] Canadian Standards Association. (2006). Canadian Highway Bridge Design Code. CAN/CSA-S6-06. Ontario.

[14] Canadian Standards Association. (2014). Canadian Highway Bridge Design Code. CAN/CSA-S6-14. Ontario.

[15] European committee for standardization. (2004). European standard: Eurocode7 Geotechnical Design Part 1: General rules. EN 1997-1:2004. Brussels.

[16] European committee for standardization. (2004). European standard: Eurocode7 Geotechnical Design Part 2: Ground investigation and testing. EN 1997-2:2004. Brussels.

[17] Fellenius, B.H. (2014). Piled foundation design as reflected in codes and standards. Proceedings of the DFI-EFFC International Conference on Piling and Deep Foundations, 21-23 May 2014 (pp 1013-1030). Stockholm.

[18] Fenton, G.A., Naghibi, F., Dundas, D., Bathurst, R.J.& Griffiths, D.V. (2016) Reliability-Based Geotechnical Design in the 2014 Canadian Highway Bridge Design Code. *Can. Geotech. J.* 53(2), 236-251. DOI: 10.1139/cgj-2015-0158.

[19] Khabbaz, H. & Aung, Y. (2015). Anchored wall design: comparing the global and partial factors of safety incorporating the Australian standards. *International Journal of Geomate* 9(1), 1395-1402. DOI:10.21660/2015.17.4291.

[20] Lewandowska, A.S. & Czajewska, M.M. (2007). Design of diaphragm walls according to EN 1997-1:2004 Eurocode 7. Proceedings of the 14th European Conference on Soil Mechanics and Geotechnical Engineering, 2007 (pp 291-296). Madrid: IOS Press.

[21] Simpson, B. (2000). Partial factors: where to apply them? International Workshop on Limit State Design in Geotechnical Engineering, 18 November 2000. Melbourne.

[22] Standards Australia. (2002). Australian standard: Earth Retaining Structures. AS 4678-2002. Sydney.

[23] Standards Australia. (2002). Structural design actions-permanent, imposed and other actions. AS/NZS 1170-1-2002. Sydney.

[24] Standards Australia. (2004). Australian standard: Bridge design Part 3 Foundations and soil-supporting structures. AS 5100-3-2004. Sydney.

[25] Tabsh, S.W. (2013). Comparison between reinforced concrete designs based on the ACI 318 and BS 8110 codes. *Structural Engineering & Mechanics*. 48(4), 467-477. DOI: 10.12989/sem.2013.48.4.467.

[26] Wijaya, J. & Taiebat, H. (2009). Factor of safety in AS- 4678: Earth retaining structures. *Australian Geomechanics Journal*. 44 (4), 27-31.