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깊은 보의 스트럿-타이 모델과 고전적인 방법의 설계 비교

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Comparison of Deep Beam Designed by Two Models of STM and ACI Traditional

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Abstract: Deep beam shall be designed either by taking into account nonlinear distribution of strain or by Appendix A of Strut-and-Tie Models (STM) according to ACI 318(M) from version of 2002. Although STM is accepted as tool in design Discontinuity region (D-region) which mostly exist in Deep beam, Corbels, Dapped ends etc., it has been modified by many researchers. In this study we design deep beam by STMs which use simple truss for load distribution and the model of complex truss for load distribution compare with the ACI traditional which is designed by flexure design method and shear provided by concrete(V_c) as provided in special provisions section of 11.8 in ACI 318-99 [1]. This study aims to find the different and efficiency of deep beam design based on variation of parameter compiled from many samples selected from ACI traditional and two model of STMs, simple and complex load distribution.

Key Words: Strut-and-Tie Models, Deep Beam, Traditional Design, ACI Design, Parameter study

1. INTRODUCTION

Reinforced Concrete Deep beam is an important structure element which its design method is one of the most popular subjects in research. ACI 318-99, clause 11.8-Special provisions for deep flexural members, RC deep beam is designed by nonlinear distribution of strain and it provides specific shear strength V_c and V_s and minimum requirement of shear reinforcement A_v and A_{vh} in clause 11.8.7 through 11.8.10 respectively whereas later version of ACI 318(s) (after ACI 318M-99) do not provide specific provision of V_c and V_s for deep beam. Only Area of shear reinforcement A_v and A_{vh} are provided in clause 11.7.4.1 and 11.7.4.2 respectively. However, RC deep beam still can be design by ACI flexure design and in this study we base on ACI 318M-11 [2] accept design of V_c and V_s that are based on ACI 318M-99. And this design is still taken into account for many designers and researchers in field of study and research. Strut-and-Tie Models (STM) is recognized in ACI from version of ACI 318M-02, STM is partly

주요어: 스트럿-타이 모델, 깊은 보, 고전적인 설계법, ACI 설계법, 파라미터 연구

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described in appendix A, and numerous investigations and modifications of the method have been performed. A STM reduces complex states of stress within a D-region of a reinforced or prestressed concrete member into a truss comprised of simple, uniaxial stress paths. Each uniaxial stress path is considered a member of the STM. It considers the complete flow of forces rather than the forces at any one particular section. The internal load path in cracked reinforced concrete is approximated by an idealized truss, where zones of concrete with primarily unidirectional compressive stresses are modeled by compression strut, tension ties are used to model the principal reinforcement, and nodal zones are typically determined by finding the product of the concrete compressive strength and a reduction factor. STM do not separate flexural and shear design, unlike traditional design.

2. DEEP BEAM DESIGN

2.1 Deep Beam Design by STM(s)

STM is a visualizing loading path by truss analogy made up of struts [3], subjected to compression and represent where the concrete should be placed, and ties, subjected to tension and represent where the reinforcement should be placed, connected at nodes and it is capable of transferring the factored loads to the supports or to adjacent B-regions. STM do not separate flexural and shear design. With the forces in each strut and tie determined from basic statics, the resulting stresses within the elements themselves must be compared with specification permissible values. Checking must be done to control failure which may occurs by yielding of the tension ties, failure of the bar anchorage, or failure of the nodal zones. Fig.1 and Fig.2 below illustrate truss geometry in STM models used in this study.

2.2 Deep Beam by ACI Traditional Design

In design of RC Deep beam by traditional design there are two major parts including flexural reinforcement and shear designs. In flexural reinforcement part, we find area of reinforcement, find the effective depth (d) and check with the area reinforcement condition provided by ACI-318M 11 [2] (clause 10.5, equation 10-3) for shear reinforcement, we check factored shear force at section (V_n) to be less than or equal to nominal shear force (V_n) ACI 318M-11, 10.7.8) and then check for shear reinforcement requirement if V_u is greater than half of V_c shear reinforcement is required.

3. PARAMETER STUDY

Two parameters of depth of beam and load location to the center of the support (load on left to center of left support and load on right to center of right support). First we select depth of beam from 0.9m to 1.8m with incremental of 0.1m in correlation with the clear span to depth ratio of 4 to 2 respectively; 4 is the maximum of clear span to depth ratio for deep beam condition. The second parameter is distant of load location (from load to the center of support). The distant are from 0.4m to 1.3m (0.1m incremental) with the angle of 64° to 26° (26.6° or 25° is the limit for deep beam) in correlation with three type of depth beam of 0.9 (ln/h = 4), 1.3 (ln/h=3) and 1.8 (ln/h=2). In order to get effectively and efficiency of this study, we wrote a design calculation program in excel VBA which we can get results, chart and drawing. Reinforcement requirements are used for the comparison. The result of the first parameter studies are shown in Fig.5 and the result of the second parameter studies are shown in Fig.6 to Fig.8 respectively.

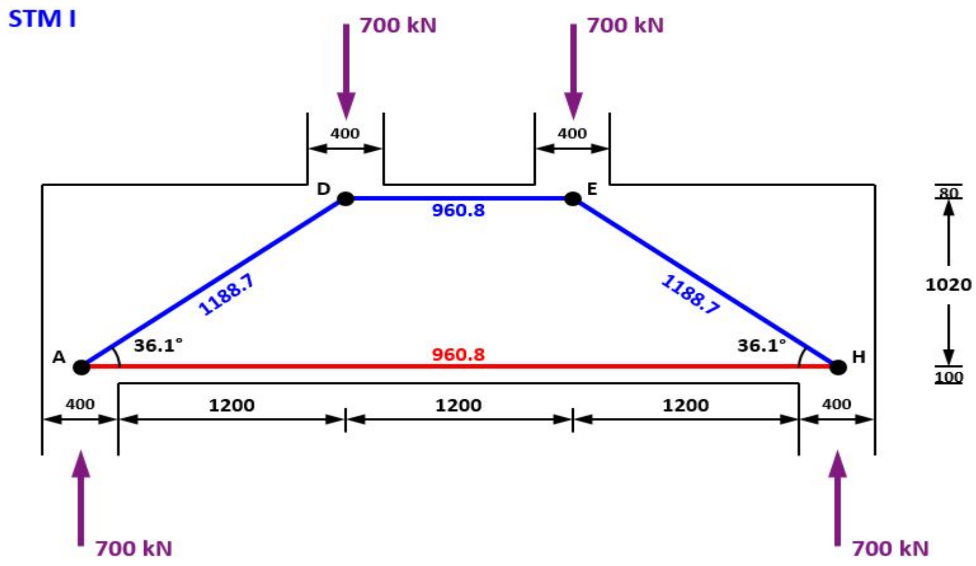


Fig. 1 Strut-Tie-Model I (Simple Load Distribution)

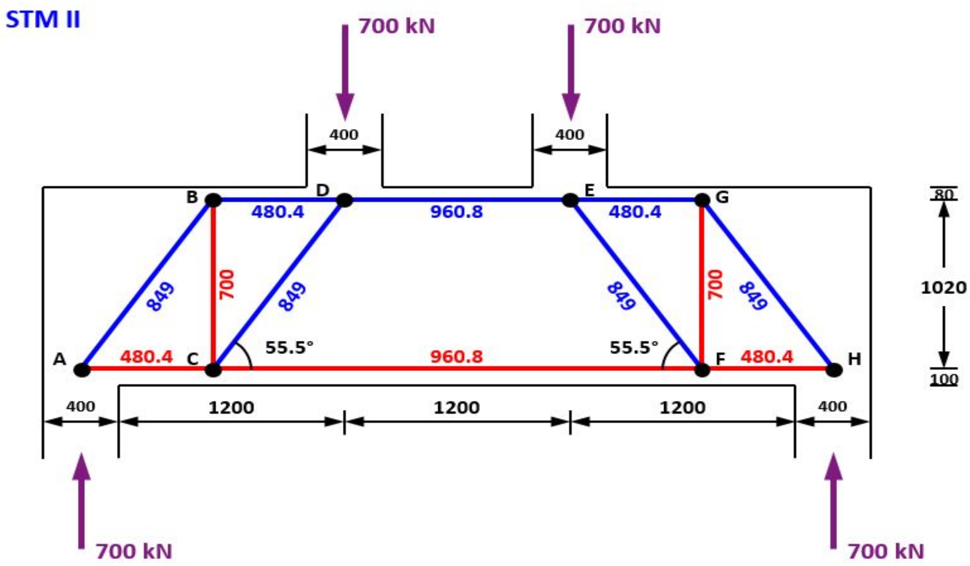


Fig. 2 Strut-Tie-Model II (Complex Load Distribution)

Table 1. Result from 46 Samples by Parameter of Height of Beam and Load Location

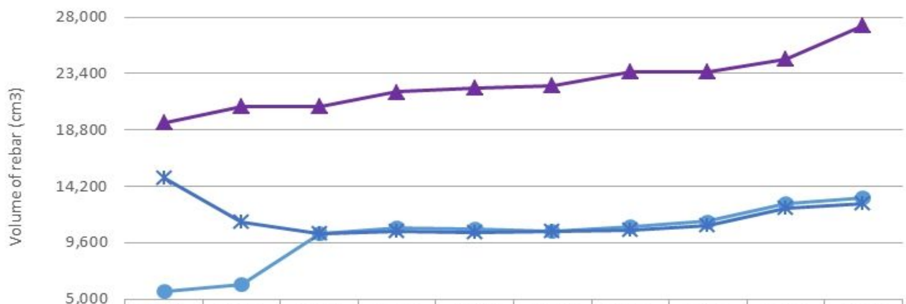
No.	Type of sample	Var. in H (mm)	Ln/h	STM1		STM2		Traditional		STM1/Trad. (Vs)	STM2/Trad. (Vt)
				Vs	Vt	Vs	Vt	Vs	Vt		
1	DB-01	900	4.00	23966.91	29618.602	23966.91	43310.55	17430.48	32305.62	0.9	1.3
2	DB-01	1000	3.60	19609.29	25816.186	19609.29	40303.41	15251.67	26515.3	1.0	1.5
3	DB-01	1110	3.24	17430.48	27743.86	17430.48	38172.264	13072.86	23386.24	1.2	1.6
4	DB-01	1200	3.00	15251.67	26021.17	15251.67	37137.39	13072.86	23576.29	1.1	1.6
5	DB-01	1300	2.77	13072.86	23766.34	13072.86	35316.06	10894.05	21296.12	1.1	1.7
6	DB-01	1400	2.57	13072.86	23588.96	13072.86	35514.66	10894.05	21410.15	1.1	1.7
7	DB-01	1500	2.40	10894.05	21815.59	10894.05	34448.01	10894.05	21473.5	1.0	1.6

8	DB-01	1600	2.25	10894.05	22221.03	10894.05	34408.29	8715.24	19674.79	1.1	1.7
9	DB-01	1700	2.12	10894.05	23716.09	10894.05	35441.01	8715.24	21144.51	1.1	1.7
10	DB-01	1800	2.00	8715.24	21942.72	8715.24	36002.88	8715.24	21524.61	1.0	1.7
		Load loc.	angle								
11	DB-02	400	64.3	6536.43	12373.19	6536.43	24092.67	4357.62	10301.15	1.2	2.3
12	DB-02	500	58.3	6536.43	12373.19	6536.43	24092.67	6536.43	12479.96	1.0	1.9
13	DB-02	600	53.1	8715.24	14552	8715.24	28575.24	6536.43	15456.11	0.9	1.8
14	DB-02	700	48.1	10894.05	16730.81	10894.05	30754.05	8715.24	17634.92	0.9	1.7
15	DB-02	800	43.3	10894.05	16730.81	10894.05	30754.05	8715.24	17634.92	0.9	1.7
16	DB-02	900	39.4	13072.86	18297.472	13072.86	31224.9	10894.05	20003.78	0.9	1.6
17	DB-02	1000	35.8	15251.67	20476.282	15251.67	33403.71	13072.86	22562.69	0.9	1.5
18	DB-02	1100	32.1	17430.48	22868.632	17430.48	36178.32	13072.86	24032.41	1.0	1.5
19	DB-02	1200	29	19609.29	25047.442	19609.29	38357.13	15251.67	29531.01	0.8	1.3
20	DB-02	1300	26	21788.1	27226.252	21788.1	40535.94	15251.67	29531.01	0.9	1.4
21	DB-02	1400	**23.2**	23966.91	29618.602	23966.91	43310.55	17430.48	32305.62	0.9	1.3
22	DB-02	1500	**20.3**	28324.53	33976.222	28324.53	47668.17	19609.29	34484.43	1.0	1.4
23	DB-03	400	70.7	4357.62	14594.98	4357.62	25409.22	4357.62	14594.98	1.0	1.7
24	DB-03	500	66.2	6536.43	16773.79	6536.43	27588.03	4357.62	14594.98	1.1	1.9
25	DB-03	600	61.9	6536.43	16773.79	6536.43	27588.03	6536.43	16773.79	1.0	1.6
26	DB-03	700	57.8	6536.43	16773.79	6536.43	27588.03	6536.43	16773.79	1.0	1.6
27	DB-03	800	54	8715.24	19484.74	8715.24	30600.96	6536.43	17039.86	1.1	1.8
28	DB-03	900	50.5	8715.24	19484.74	8715.24	30600.96	8715.24	19218.67	1.0	1.6
29	DB-03	1000	47.1	10894.05	21663.55	10894.05	32779.77	8715.24	19218.67	1.1	1.7
30	DB-03	1100	43.9	10894.05	21663.55	10894.05	32779.77	10894.05	21397.48	1.0	1.5
31	DB-03	1200	41.1	13072.86	23842.36	13072.86	34958.58	10894.05	21397.48	1.1	1.6
32	DB-03	1300	38.5	13072.86	23842.36	13072.86	34958.58	10894.05	21397.48	1.1	1.6
33	DB-03	1400	36.1	15251.67	26021.17	15251.67	37137.39	13072.86	23576.29	1.1	1.6
34	DB-03	1500	33.7	15251.67	26021.17	15251.67	37137.39	13072.86	23842.36	1.1	1.6
35	DB-04	400	77.2	4357.62	17585.1	4357.62	31645.26	2178.81	14988.18	1.2	2.1
36	DB-04	500	74.1	4357.62	17585.1	4357.62	31645.26	4357.62	17166.99	1.0	1.8
37	DB-04	600	71	4357.62	17585.1	4357.62	31645.26	4357.62	17166.99	1.0	1.8
38	DB-04	700	68.1	4357.62	17585.1	4357.62	31645.26	4357.62	17166.99	1.0	1.8
39	DB-04	800	65.2	6536.43	19763.91	6536.43	33824.07	4357.62	17166.99	1.2	2.0
40	DB-04	900	62.4	6536.43	19763.91	6536.43	33824.07	6536.43	19345.8	1.0	1.7
41	DB-04	1000	59.8	6536.43	19763.91	6536.43	33824.07	6536.43	19345.8	1.0	1.7
42	DB-04	1100	57.2	6536.43	19763.91	6536.43	33824.07	6536.43	19345.8	1.0	1.7
43	DB-04	1200	54.8	8715.24	21942.72	8715.24	36002.88	6536.43	19345.8	1.1	1.9
44	DB-04	1300	52.4	8715.24	21942.72	8715.24	36002.88	8715.24	21524.61	1.0	1.7
45	DB-04	1400	50.3	8715.24	21942.72	8715.24	36002.88	8715.24	21524.61	1.0	1.7
46	DB-04	1500	48.2	10894.05	24121.53	10894.05	38181.69	8715.24	21524.61	1.1	1.8

4. COMPARISON OF DESIGN METHOD BY PARAMETER STUDY

According to the result of this case study we find that for stirrup rebar, STM1 and Traditional require similar amount of rebar from the clear span to depth ratio 3 to 2 but contrast in demand from clear span to depth ratio of 4 to 3 and STM2 requires more rebar comparing to STM1 and Traditional. Because tension tie in vertical (BC and GF) are added it is different from STM1 as shown in Fig.3. For main rebar, in general, reinforcement decrease when depth of beam increase.

Particularly, STM1 and STM2 require same amount of rebar as shown in Fig.4. But actually by tension force (see Fig.1 and Fig. 2) STM2 should require main rebar less than STM1 base on the value of force in tension, but in case of requirement of anchorage length is more than the provision of anchorage length, the two models will meet the same requirement. Thus, in the first parameter study of clear span to depth ratio, STM2 requires total rebar more than STM1 and Traditional (Fig. 5). And these requirements of rebar seem to be decreased inversely with the increase depth of the beam. For second parameter studies of load location, as mention above, we divide into 3 case of clear span to depth ratio equal to 4, 3 and 2. Total of rebar increases when distant of load to center of support increase and it gets more effect with the short depth of beam than the deep one.

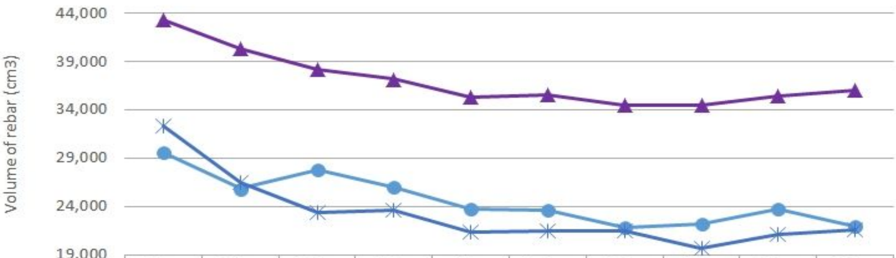


	0.9 m	1.0 m	1.1 m	1.2 m	1.3 m	1.4 m	1.5 m	1.6 m	1.7 m	1.8 m
STM1	5,651.7	6,206.9	10,313.4	10,769.5	10,693.5	10,516.1	10,921.5	11,327.0	12,822.0	13,227.5
STM2	19,343.6	20,694.1	20,741.8	21,885.7	22,243.2	22,441.8	23,554.0	23,514.2	24,547.0	27,287.6
Trad.	14,875.1	11,263.6	10,313.4	10,503.4	10,402.1	10,516.1	10,579.5	10,959.6	12,429.3	12,809.4

Fig. 3 Volume of Stirrup by Variation of ln/h (h=0.9m-1.8m, ln/h=4-2)

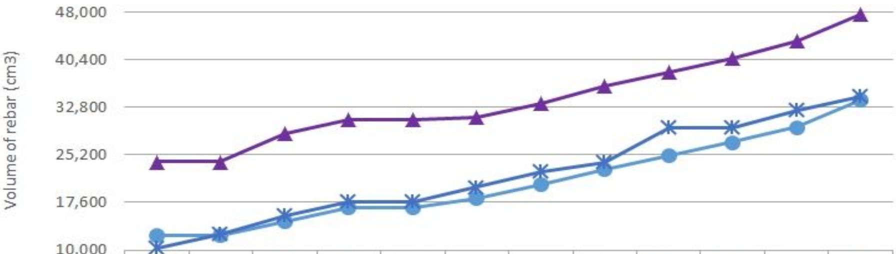
	0.9 m	1.0 m	1.1 m	1.2 m	1.3 m	1.4 m	1.5 m	1.6 m	1.7 m	1.8 m
STM1	23,966.9	19,609.3	17,430.5	15,251.7	13,072.9	13,072.9	10,894.1	10,894.1	10,894.1	8,715.2
STM2	23,966.9	19,609.3	17,430.5	15,251.7	13,072.9	13,072.9	10,894.1	10,894.1	10,894.1	8,715.2
Trad.	17,430.5	15,251.7	13,072.9	13,072.9	10,894.1	10,894.1	10,894.1	8,715.2	8,715.2	8,715.2

Fig. 4 Volume of Main Rebar by Variation of ln/h (h=0.9m-1.8m, ln/h=4-2)



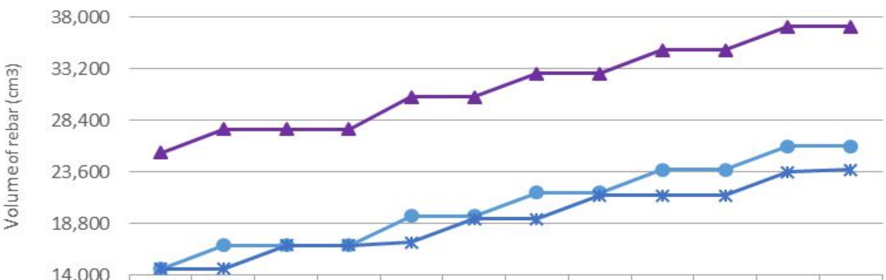
	0.9 m	1.0 m	1.1 m	1.2 m	1.3 m	1.4 m	1.5 m	1.6 m	1.7 m	1.8 m
STM1	29,618.6	25,816.2	27,743.9	26,021.2	23,766.3	23,589.0	21,815.6	22,221.0	23,716.1	21,942.7
STM2	43,310.6	40,303.4	38,172.3	37,137.4	35,316.1	35,514.7	34,448.0	34,408.3	35,441.0	36,002.9
Trad.	32,305.6	26,515.3	23,386.2	23,576.3	21,296.1	21,410.2	21,473.5	19,674.8	21,144.5	21,524.6

Fig. 5 Total Volume of Steel by Variation of ln/h (h=0.9m-1.8m, ln/h=4-2)



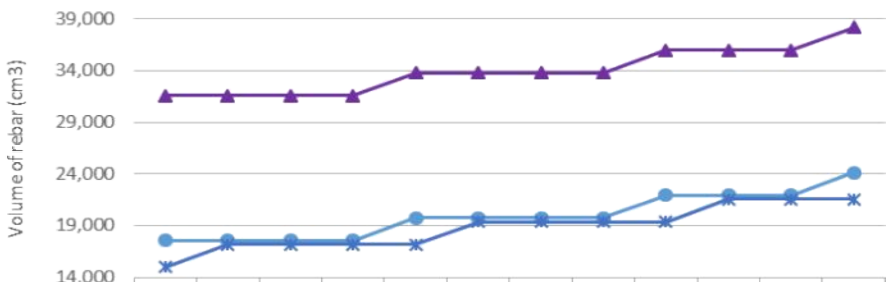
	0.4 m	0.5 m	0.6 m	0.7 m	0.8 m	0.9 m	1 m	1.1 m	1.2 m	1.3 m	1.4 m	1.5 m
STM1	12,373.	12,373.	14,552.	16,730.	16,730.	18,297.	20,476.	22,868.	25,047.	27,226.	29,618.	33,976.
STM2	24,092.	24,092.	28,575.	30,754.	30,754.	31,224.	33,403.	36,178.	38,357.	40,535.	43,310.	47,668.
Trad.	10,301.	12,480.	15,456.	17,634.	17,634.	20,003.	22,562.	24,032.	29,531.	29,531.	32,305.	34,484.

Fig. 6 Total Volume of Steel by Load Location Variation when ln/h=4 (DB-02)



	0.4m	0.5m	0.6m	0.7m	0.8m	0.9m	1m	1.1m	1.2m	1.3m	1.4m	1.5m
STM1	14,595	16,773	16,773	16,773	19,484	19,484	21,663	21,663	23,842	23,842	26,021	26,021
STM2	25,409	27,588	27,588	27,588	30,601	30,601	32,779	32,779	34,958	34,958	37,137	37,137
Trad.	14,595	14,595	16,773	16,773	17,039	19,218	19,218	21,397	21,397	21,397	23,576	23,842

Fig. 7 Total Volume of Steelby Load Location Variation when ln/h = 3 (DB-03)



	0.4 m	0.5 m	0.6 m	0.7 m	0.8 m	0.9 m	1 m	1.1 m	1.2 m	1.3 m	1.4 m	1.5 m
STM1	17,585	17,585	17,585	17,585	19,763	19,763	19,763	19,763	21,942	21,942	21,942	24,121
STM2	31,645	31,645	31,645	31,645	33,824	33,824	33,824	33,824	36,002	36,002	36,002	38,181
Trad.	14,988	17,167	17,167	17,167	17,167	19,345	19,345	19,345	19,345	21,524	21,524	21,524

Fig. 8 Total Volume of Steel by Load Location Variation when ln/h = 2 (DB-04)

5. CONCLUSION

This study shows that a deep beam with symmetric loading designed by STM requires steel more than by Traditional in general and STM2 (complex load distribution) requires steel more than STM1 (simple load distribution). In addition, when clear span to depth ration is near 4 (shallow) variation of shear requirement is higher than when clear span to depth is close from 3 to 2 for all three methods. For total rebar, STM1 requires about 10% and STM2 about 60% more than ACI Traditional design method. Although this study is in small scope we hope that it can be a useful guide for further research of deep beam designed by strut-and-tie model and ACI Traditional. More parameters and samples need to be done in order to get more accuracy result and to extend knowledge.

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