Fourth International Conference on Construction in the 21st Century (CITC-IV)
"Accelerating Innovation in Engineering, Management and Technology"
July 11-13, 2007, Gold Coast, Australia

Simplified Design For Torsion In Beams

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Abstract

Research work is focused on suggesting a simplified and economical design for the compatibility torsion in reinforced concrete beams. Edges beams and beams supporting unequal spans or loading are usually subjected to torsion. ACI code allows 100% redistribution of compatibility torque. This research work focuses on the effect of modification of torsion constant on the final cost of steel reinforcement. Following the conclusions of this work, torsion reinforcement can either be minimized or eliminated in beams by increasing a small amount of flexural steel in adjoining beams. Significant saving in cost of steel can be achieved by following the suggested approach.

Keywords
Compatibility Torsion, Torsion Constant.

1. Introduction

Structural engineers frequently come across the torsion design of members during their professional practice. Some of them prefer to design beams for the actual torsion as it is developed, others, especially when using software for analysis, opt to modify the properties i.e. modify torsion constant in order to minimize torsion, wherever possible. By modifying properties they manage to reduce torsion and finally achieve simplification in detailing and construction by either minimizing or eliminating torsion reinforcement.

This research work is carried out to develop a guideline for structural engineers that whether the torsion constant should be modified or not in order to get a more economical design. Comparison between internal forces, steel reinforcement and cost is presented for various structural systems for modified and unmodified conditions to conclude for a better option.

2. Methodology

By reducing the torsion constants of beams the amount of compatibility twisting moment reduces with a corresponding increase in the bending moments of adjoining members. Ultimately it results in reduction of torsion steel requirement for main beams and increase in amount of flexural steel in other secondary beams. Torsion constant for main beams is reduced from 1.00 to 0.00 in steps and results of twisting moment, bending moment and amount of steel are presented in forthcoming tables. Discussion of results is mainly focused on the comparison of results for torsion constant reducing from 1.00 to 0.10. A cost comparison between the two options is presented to reach at the most economical design

3. Results Of Analysis And Design

All structural analysis is carried out on ETABS, a software based on finite element method. It provides facility of modification of various properties of structural elements. Analysis is performed on four single story space frames which are one, two, three and four bay. Structures are modeled in a way that secondary breams would produce torsion in primary beams. Following are the material and structural properties and loading for the frames:

- Main beams: 9” x 24”, Secondary beams: 9” x 18”
- All columns: 18” x 18”
- fc' = 3000 psi, f_y = 60,000 psi
- Storey height = 12’
- Live Load = 150 psf, Imposed dead Load = 150 psf
- Load combinations: 1.2 D.L. + 1.6 L.L.

The material properties and sizes of beams and columns are those which are most frequently used in buildings. Live and dead loads are kept a little higher to have significant values of internal forces and steel reinforcement areas so that the results can be easily evaluated. All bending moment values are in kip-ft and steel reinforcement areas in in^2.

3.1 Single Bay Structure

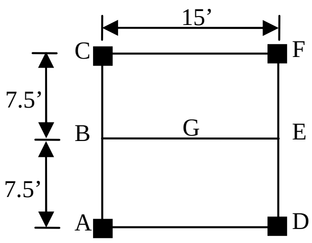

Figure 1: Plan Of Single Bay Single Story Space Frame

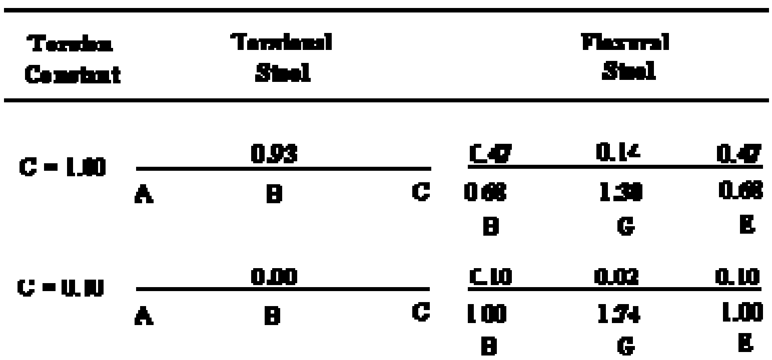

Figure 2: Comparison Of Longitudinal Steel Reinforcement

Table 1: Comparison Of Bending Moments And Steel Areas

Torsion Constant (C) of Main Beams	Element AB, BC, DE, EF		Moment in ABC and DEF		Moment in Beam BGE	Bottom Flexural Longitudinal Steel Required At G
	Magnitude of Torsion	Longitudinal Steel Area Required For Torsion	M_A M_C M_D M_F	M_B M_E	M_G	
1.00	12.98	0.93	-32.61	71.94	71.85	1.30
0.80	11.47	0.82	-32.61	71.94	74.86	1.34
0.60	9.61	0.75	-32.61	71.94	78.58	1.42
0.40	7.26	0.79	-32.61	71.94	83.29	1.52
0.20	4.18	0.77	-32.61	71.94	89.44	1.65
0.10	2.26	0.00	-32.61	71.94	93.28	1.74
0.00	0.00	0.00	-32.61	71.94	97.81	1.84
Difference b/w C = 1.00 & 0.10	-10.72	-0.93	0.00	0.00	21.43	0.44
% Difference b/w C = 1.00 & 0.10	-82.59%	-100.00%	0.00%	0.00%	36.13%	41.54%

3.1.1 Comments

By decreasing torsion constant (C) from 1.00 to 0.10 for main beams (ABC & DEF) the torsion reinforcement is reduced from 0.93 to 0.00 but the corresponding increase in bottom steel area in rib (BGE) at mid point G is only 0.44 (from 1.30 to 1.74). Savings in reinforcement cost is as follows:

Reinforcement area saved	= 0.93 – 0.44 = 0.49 in^2
Length of beam	= 15.00 ft
Volume of steel	= 0.49/144.00 x 15.00 = 0.05 ft^3
Weight of steel	= 0.05 x 490.00 = 24.50 lbs
Saving per running ft	= 24.50/15.00 = 1.63 lbs/ft
Rate of steel	= 30.00 Rs./lbs
Amount saved	= 1.63 x 30.00 = 48.90 Rs./ft = 0.82 US$/ft **(in Pakistan)**

3.2 Two Bay Structure

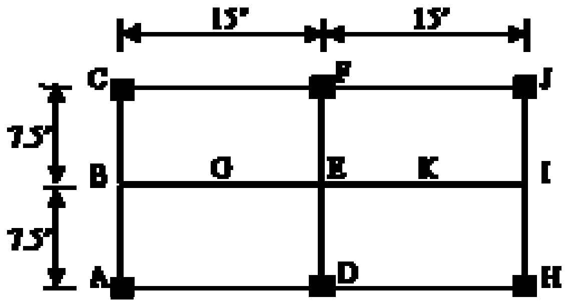

Figure 3: Plan Of Two Bay Single Story Space Frame

3.2.1 Comments

By decreasing ‘C’ from 1.00 to 0.10 for main beams (ABC, DEF & HIJ) the torsion reinforcement in

ABC & HIJ is reduced from 0.77 to 0.00 but the corresponding increase in bottom steel area in rib is only 0.07 (from 1.08 to 1.15). Savings in reinforcement cost is as follows:

Reinforcement area saved	= 0.77 – 0.07 = 0.70 in^2
Volume of steel	= 0.70/144.00 x 15.00 = 0.07 ft^3
Weight of steel	= 0.07 x 490.00 = 34.30 lbs
Saving per running ft	= 2.29 lbs/ft
Rate of steel	= 30.00 Rs./lbs
Amount saved	= 68.70 Rs./ft = 1.15 US$/ft

Table 2: Comparison Of Bending Moments And Steel Areas

Torsion Constant (C) of Main Beams	Element AB, CB, HI, IJ		Moment in ABC And HIJ		Moment in Beam BGE And EIK	
	Magnitude of Torsion	Longitudinal Steel Area For Torsion	M_A M_C M_H M_J	M_B M_I	M_G M_K	M_E
1.00	10.73	0.77	-28.71	64.10	53.19	-73.57
0.80	9.21	0.77	-28.43	63.41	54.29	-74.87
0.60	7.46	0.79	-28.10	62.61	55.57	-76.38
0.40	5.41	0.76	-27.27	61.86	57.06	-78.16
0.20	2.96	0.77	-27.26	60.56	58.84	-80.27
0.10	1.55	0.00	-26.99	52.92	59.87	-81.48
0.00	0.00	0.00	-26.70	59.21	61.00	-82.82
Difference b/w C = 1.00 & 0.10	-9.18	-0.77	1.72	-11.18	6.68	-7.91
% Difference b/w C = 1.00 & 0.10	-85.55%	-100.00%	-5.99%	-17.44%	12.56%	10.75%

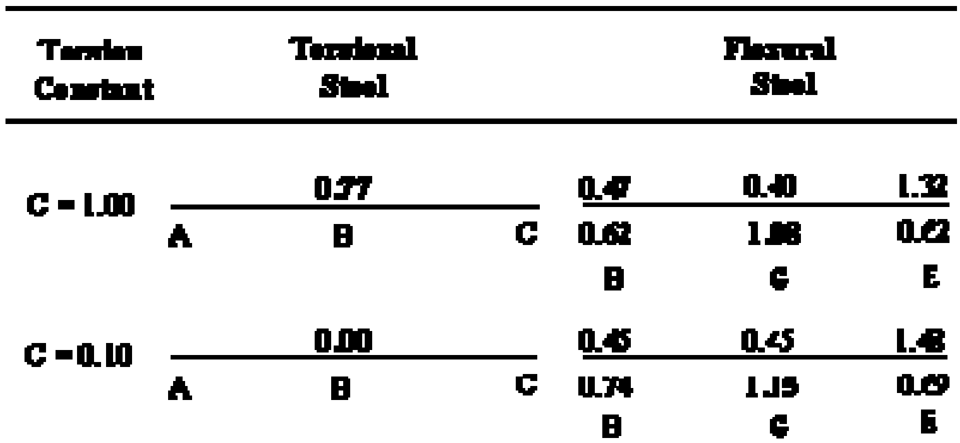

Figure 4: Comparison Of Longitudinal Steel Reinforcement

3.3 Three Bay Structure

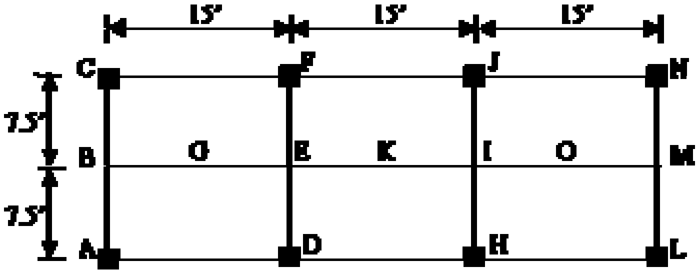

Figure 5: Plan Of Three Bay Single Story Space Frame

Table 3: Comparison Of Bending Moments And Steel Areas

Torsion Constant (C) of Main Beams	Element AB, BC		Moment in ABC And LMN		Moment in Beam BGE	
	Magnitude of Torsion	Longitudinal Steel Area For Torsion	M_A M_C M_L M_N	M_B M_M	M_G	M_E
1	10.97	0.78	-29.1	64.94	55.11	-68.65
0.5	6.73	0.79	-28.47	63.37	59.24	-69.93
0.1	1.65	0	-27.74	61.58	64.43	-70.97
0	0	0	-27.51	61.01	66.16	-71.21
Difference b/w C = 1.00 & 0.10	-9.32	-0.78	-1.36	-3.36	9.32	2.32
% Difference b/w C = 1.00 & 0.10	-84.96%	-100.00%	-4.67%	-5.17%	16.91%	3.38%

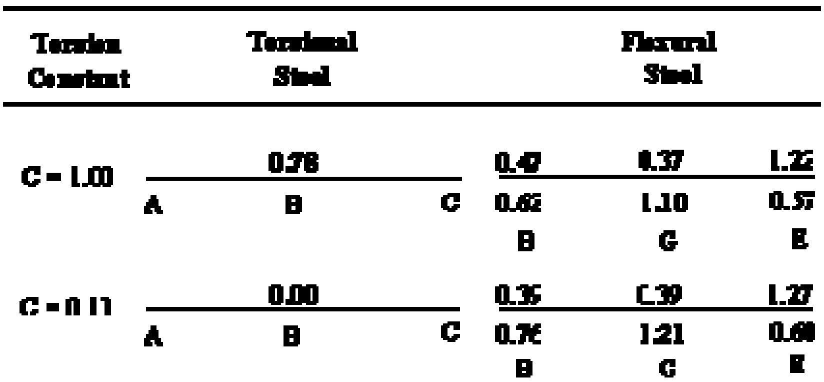

Figure 6: Comparison Of Longitudinal Steel Reinforcement

3.3.1 Comments

By decreasing 'C' from 1.00 to 0.10 for main beams the torsion reinforcement in rib (ABC) is reduced from 0.78 to 0.00 but the corresponding increase in positive steel area at point G is only 0.11 (from 1.10 to 1.21). Savings in reinforcement cost is as follows:

Reinforcement area saved = 0.78 – 0.11 = 0.67 in^2
Volume of steel = 0.07 ft^3
Weight of steel = 34.30 lbs
Saving per running ft = 2.29 lbs/ft
Amount saved = 68.70 Rs./ft = 1.15 US$/ft

3.4 Four Bay Structure

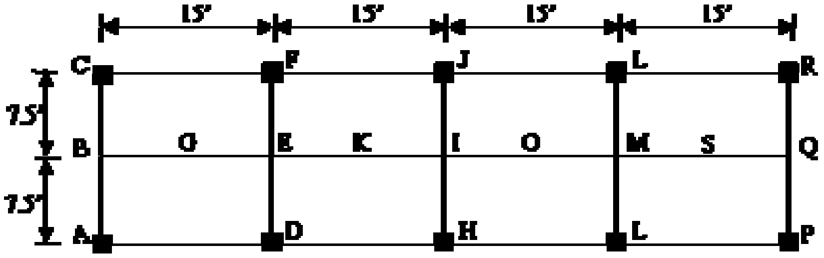

Figure 7: Plan Of Four Bay Single Story Space Frame

Table 4: Comparison Of Bending Moments And Steel Areas

Torsion Constant (C) of Main Beams	Element AB, BC		Moment in ABC		Moment in Beam BGE	
	Magnitude of Torsion	Long. Steel Area For Torsion	M_A M_C	M_B	M_G	M_E
1	10.92	0.78	-26.97	66.97	55.01	-69.00
0.5	6.69	0.79	-26.34	65.29	58.92	-70.77
0.1	1.64	0	-25.61	63.35	63.73	-72.57
0	0	0	-25.37	62.72	65.32	-73.10
Difference b/w C = 1.00 & 0.10	-9.28	-0.78	-1.36	-3.62	8.72	3.57
% Difference b/w C = 1.00 & 0.10	-84.98%	-100.00%	-5.04%	-5.41%	15.85%	5.17%

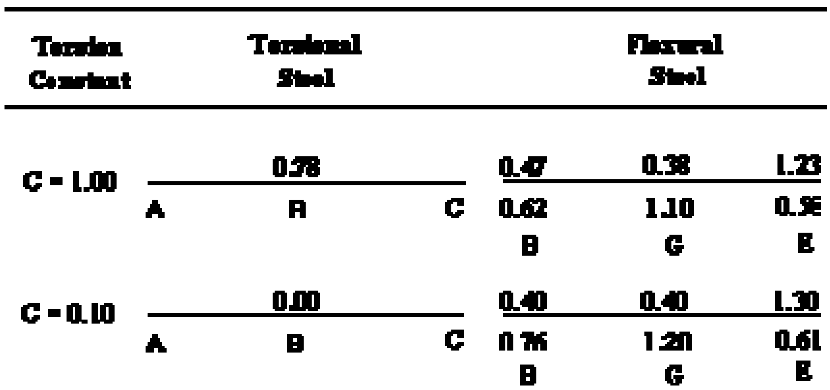

Figure 8: Comparison Of Longitudinal Steel Reinforcement

3.4.1 Comment

By decreasing ‘C’ from 1.00 to 0.10 for main beams the torsion reinforcement in ABC is reduced from 0.78 to 0.00 but the corresponding increase in bottom steel area at point G is only 0.10 (from 1.10 to 1.20). Savings in reinforcement cost is as follows:

Reinforcement area saved = 0.78 – 0.10 = 0.68 in^2
Volume of steel = 0.07 ft^3
Weight of steel = 34.30 lbs
Saving per running ft = 2.29 lbs/ft
Amount saved = 68.70 Rs./ft = 1.15 US$/ft

4. Conclusions

By reducing the torsion constant of main (peripheral) beam from 1.00 to 0.10 following observations are made from the studied example:

- Twisting moment in the main beam reduces by 82.00 to 84.00% and positive moment in the secondary beam increases by an amount 12.00 to 16.00% in general and 36.00% for the single bay frame.
- Negative moment at the first internal support increase by 3.00 to 5.00%.
- Amount of torsion steel required in main beams reduces by 100.00% and positive flexural steel in first span of secondary beam increases by 6.00 to 9.00% in general and 33.00% for the single bay frame.
- The comparison of internal forces and steel reinforcement cost has established that in all cases the modification of torsion constant for main beams has proved to be an economical option.
- It is preferable to keep torsion constant as 0.10 but not 0.00, as due to hanger bars and monolith joints some torsion is always developed in the main beams.

For manual design of single bay frame (as shown in Fig: 1) there is no need to check for torsion, just increase bottom flexural steel in secondary beam by 33.00% and provide minimum top steel at its junction with main beam. It will be safe and economical as well. As cracking is expected in main beam due to torsional redistribution hence, minimum torsion reinforcement must be provided for crack control.

5. Recommendations For Future Research

- Such comparison should be carried out for more complicated structures preferable having irregular framing.
- Effect of variation of member sizes, spans and material properties should be investigated.
- Results for lateral loads should also be compared to establish a more general guideline.

6. References

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