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EFFECT OF SKEW ANGLE ON BEHAVIOR OF SIMPLY SUPPORTED R. C. T-BEAM BRIDGE DECKS

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ABSTRACT

T-beam bridge is a common choice among the designers for small and medium span bridges. In order to cater to greater speed and more safety of present day traffic, the modern high ways are to be straight as far as possible. This requirement, along with other requirements for fixing alignment of the bridges, is mainly responsible for provision of increasing number of skew bridges. The presence of skew in a bridge makes the analysis and design of bridge decks intricate. For the T- beam bridges with small skew angle, it is frequently considered safe to ignore the angle of skew and analyze the bridge as a right bridge with a span equal to the skew span. However, T-beam bridges with large angle of skew can have a considerable effect on the behavior of the bridge especially in the short to medium range of spans. In this paper an analytical study using three dimensional finite element methods was performed to investigate the effect of skew angle on behavior of simply supported reinforced concrete T-beam bridge decks. The parameters investigated in this analytical study were the span lengths and skew angle. The finite element analysis (FEA) results for skewed bridges were compared to the reference straight bridges (nonskewed). The geometric dimensions of the T-beam bridge decks and the loading used are in compliance with AASHTO standard specifications. The FEA results and comparison of skewed bridge with straight bridge indicate that max. Live load bending moments and deflections decreases in T- beams for skewed bridges, while max. shear, torsion and supports reactions increases in some T-beams for skewed bridges for all considered span lengths (12, 16, 20 and 24m). This study disagreement with the AASHTO standard specifications as well as the LRFD in recommending that bridges with skew angle less than or equal 20° be designed as straight (non skewed) bridges also it recommended that engineers are better to perform three dimensional finite element analysis for skewed T-beam bridge decks.

Keywords: bridges, T-beam bridge decks, skew angle, span length.

1. INTRODUCTION

T- Beam bridge deck [1], is the most common type of bridges in Iraq and other contraries, it consists of several beams or girders. The span in the direction of the road way and connected across their tops by a thin continuous structural stab, the longitudinal beams can be made of several different materials, usually steel or concrete. The concrete deck is presented in present study.

Skewed bridges are often encountered in highway design when the geometry cannot accommodate straight bridges. Highway bridges are characterized by the angle formed with the axis of the crossed highway. The skew angle can be defined as the angle between the normal to the centerline of the bridge and the centerline of the abutment or pier cap, as described in Figure-1.

Due to high traffic speeds road or railway schemes can seldom be modified in order to eliminate the skew of their bridges. Therefore, a considerable number of skew bridge decks are constructed.

AASHTO [2] suggests that bridges with a skew angle less than as equal 20° be designed as a typical bridge at right angles with no modifications. However, if the skew angle exceeds 20°, AASHTO [2] suggest the use of an alternate superstructure configuration.

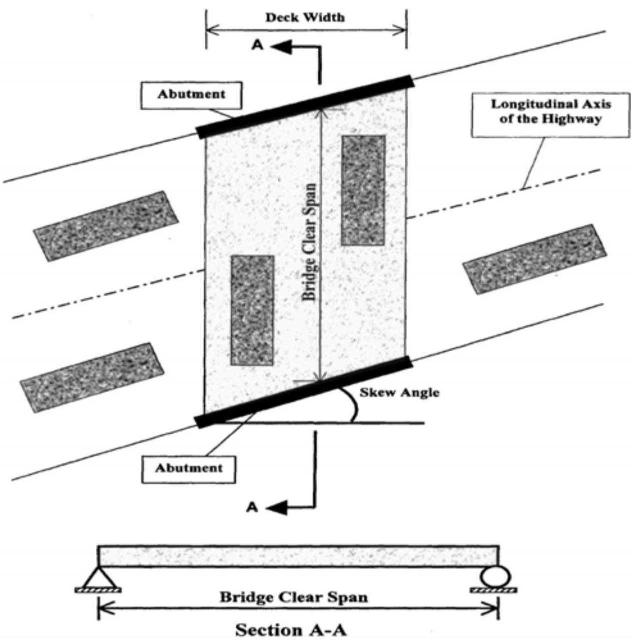

Figure-1. Description of a skewed bridge.

This study presents the results of a parametric study which evaluated the effect of skew angle on the behavior of simply supported R.C. T-beam bridge decks. Here the present study is carried out for two lane T-beam bridges decks consists of four beams and two diaphragms at ends, without footpath loaded with two HS-20 truck

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positioned according to AASHTO [2] to produce maximums of bending moments, shears, deflections, torsions and maximum supported reactions, are analyzed for 12, 16, 20 and 24m right spans with 0°, 15°, 30° and 45° skew angles. The results of skewed bridges were compared with straight bridges (skew angle = 0°).

2. PARAMETRIC STUDY

Typical simply supported, single span, two lane bridge study cases were considered in this investigation. The simple support condition is used. Four span lengths were considered in this parametric study as 12, 16, 20 and 24m, each span length consist of four longitudinal T-beams and two diaphragms at ends. The effect of skewness on the behavior of T-beam bridge decks is studied by analyze each span with skew angles 0°,15°, 30° and 45°. Straight bridges with zero skew angle served as a reference for comparison with skewed bridges. In total 16 bridge cases were analyzed and assessed using finite element analysis.

3. BRIDGE DECKS CONSIDERED IN THE PRESENT STUDY

For the purpose of this study, a 16 bridge deck models of two- Lane Bridge, each deck consist from four longitudinal T-beams and two diaphragms at ends as shown in Table-1. The models represent a simply supported bridge decks as shown in Figure-2.

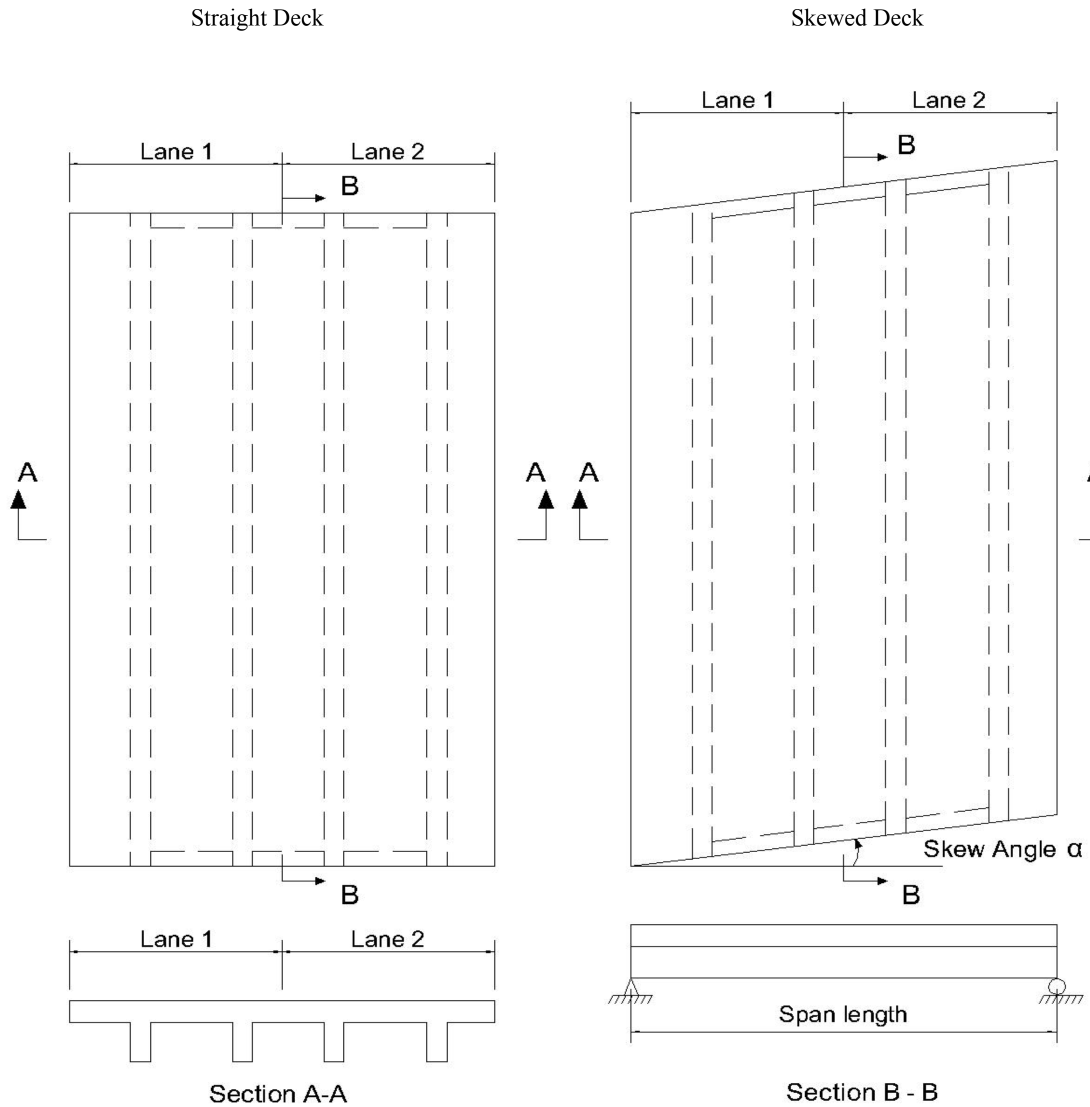

Figure-2. Bridge deck model adapted in this study.

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Table-1. Bridge decks models.

No.	Span (m)	Skew angle	No.	Span (m)	Skew angle
1	12	0°	9	20	0°
2	12	15°	10	20	15°
3	12	30°	11	20	30°
4	12	45°	12	20	45°
5	16	0°	13	24	0°
6	16	15°	14	24	15°
7	16	30°	15	24	30°
8	16	45°	16	24	45°

3.1 Geometric dimensions of T- Beam

T-beam construction consists of vertical rectangular stem with a wide top flange as shown in Figure-3; the wide top flange is usually the transversely reinforced deck slab and the riding surface for the traffic. The stem width (h_w) vary from (14 in-22 in) [2] set by the required horizontal spacing for positive moment reinforcement. The depth of wide top flanges (h_f) and stem depth (h_s) must satisfy the requirement of moments, shear and deflection under critical combination of loads.

3.2 Geometric dimensions of bridges deck models

The design of bridge decks models starts with the determination of decks width (D.W) of the two lane bridges. According to AASHTO [2] (section 3.6), the lane loading or standard truck shall be assumed to occupy a width of 10 ft (3.048 m) and these loads shall be placed in minimum 12 ft (3.658 m) wide design traffic lanes, as shown in Figure-4.

To find the minimum depth (h_f) for flange (slab) and total depth for longitudinal beams (h_t), Table (8.9.2) in AASHTO give a depth to limit deflection or any deformations that may adversely affects the strength or serviceability of the structure at service load plus impact. The details of dimensions of longitudinal beams and ends diaphragms are shown in Table-2.

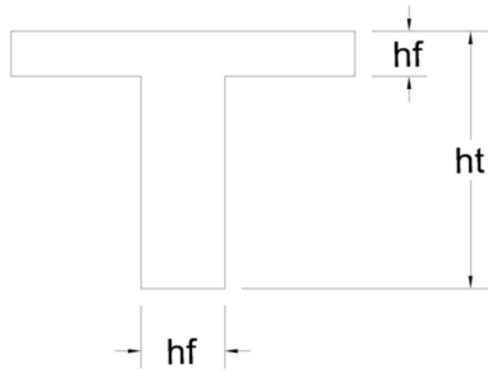

Figure-3. Section in T- Beam.

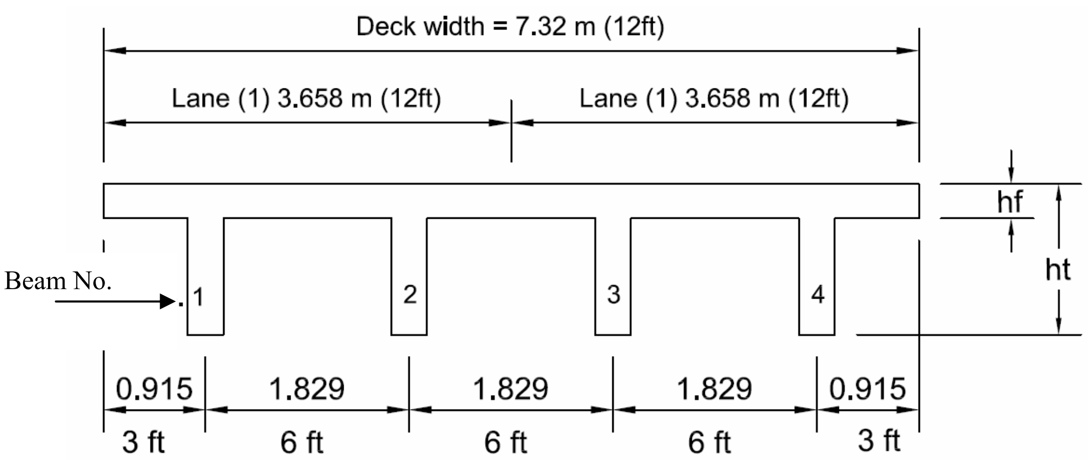

Figure-4. Transverse section of the bridge decks models.

Table-2. Dimensions of T-beams and ends diaphragms.

No.	Span (m)	Skew angle	T-beams			Ends diaphragms		
			h_w (m)	h_f (m)	h_t (m)	h_w (m)	h_f (m)	h_t (m)
1	12	0°	0.4	0.21	0.9	0.3	0.21	0.9
2	12	15°	0.4	0.21	0.9	0.3	0.21	0.9
3	12	30°	0.4	0.21	0.9	0.3	0.21	0.9
4	12	45°	0.4	0.21	0.9	0.3	0.21	0.9
5	16	0°	0.4	0.21	1.12	0.3	0.21	1.12
6	16	15°	0.4	0.21	1.12	0.3	0.21	1.12
7	16	30°	0.4	0.21	1.12	0.3	0.21	1.12
8	16	45°	0.4	0.21	1.12	0.3	0.21	1.12
9	20	0°	0.4	0.21	1.4	0.3	0.21	1.4
10	20	15°	0.4	0.21	1.4	0.3	0.21	1.4
11	20	30°	0.4	0.21	1.4	0.3	0.21	1.4
12	20	45°	0.4	0.21	1.4	0.3	0.21	1.4
13	24	0°	0.4	0.21	1.68	0.3	0.21	1.68
14	24	15°	0.4	0.21	1.68	0.3	0.21	1.68
15	24	30°	0.4	0.21	1.68	0.3	0.21	1.68
16	24	45°	0.4	0.21	1.68	0.3	0.21	1.68

4. POSITION OF LOAD ON THE BRIDGE DECK MODELS

In previous studies [4, 5] related to straight reinforced concrete slab bridges, two possible transverse loading positions of the design trucks were considered: (a) centered condition where each truck is centered in its own lane as prescribed by AASHTO [2], and (b) edge condition where the design trucks are placed close to one edge (left) of the deck, such that the center of the left wheel of the left most truck is positioned at one foot from the free edge of the deck. The distance between the adjacent trucks for the edge condition was intentionally selected for this study to be 1.2m (4ft) or 3m (l0ft) center to center spacing, in order to produce the worst live loading condition on the bridge. Placing the HS-20 truck wheel loads this close in the transverse direction (1.2m or 4ft apart) is not in accordance with the AASHTO [2] Loading requirements of one truck per lane. However, it meets AASHTO LRFD [3] section 3.6.1.3.1 provision of a minimum 1.2m (4ft) distance between the wheels of adjacent design trucks. Therefore, the FEA models and HS-20 wheel load arrangements are expected to generate higher bending moments due to this imposed live loading condition. Placing the wheel load at 0.3m (1ft) from the free edge could be considered critical or overestimating the longitudinal bending moment. However, AASHTO [2] specifies a minimum distance of 0.6m (2ft) from the curb of railing to be more realistic and practical. Therefore, bridges with edge load were reanalyzed further by placing the wheel load of left truck 0.6m (2ft) from the parapet (0.3m or 1ft) which totals 0.9m (3ft) instead of 0.3m (1ft) from the edge. The FEA results of two edge loading conditions E1 (wheel load at 0.3m or 1ft from the free edge) and E3 (wheel load at 0.9m or 3ft from the free edge) and E3 (wheel load at 0.9m or 3ft from the free edge) showed only a 5% difference. It was also shown that the "Edge Load" resulted in higher maximum moments than the "Centered Load ".

Since the objective of presents study is to investigate the effect of skew angles on behavior of simply supported R.C. T- beam bridge decks. Selected 16 two lane bridge decks models with different spans and skew angles as mentioned in section 3.2 were analyzed by placing two HS-20 truck wheel Loads using finite element analysis method. The transverse positions used for these two trucks in order to produce the worst wheel loading conditions as refer above in previous studies [4, 5] are shown in Figure-5. An increment of 0.4m is given in the longitudinal direction for moving load generation [6]. The dead load of the deck is neglected in this study.

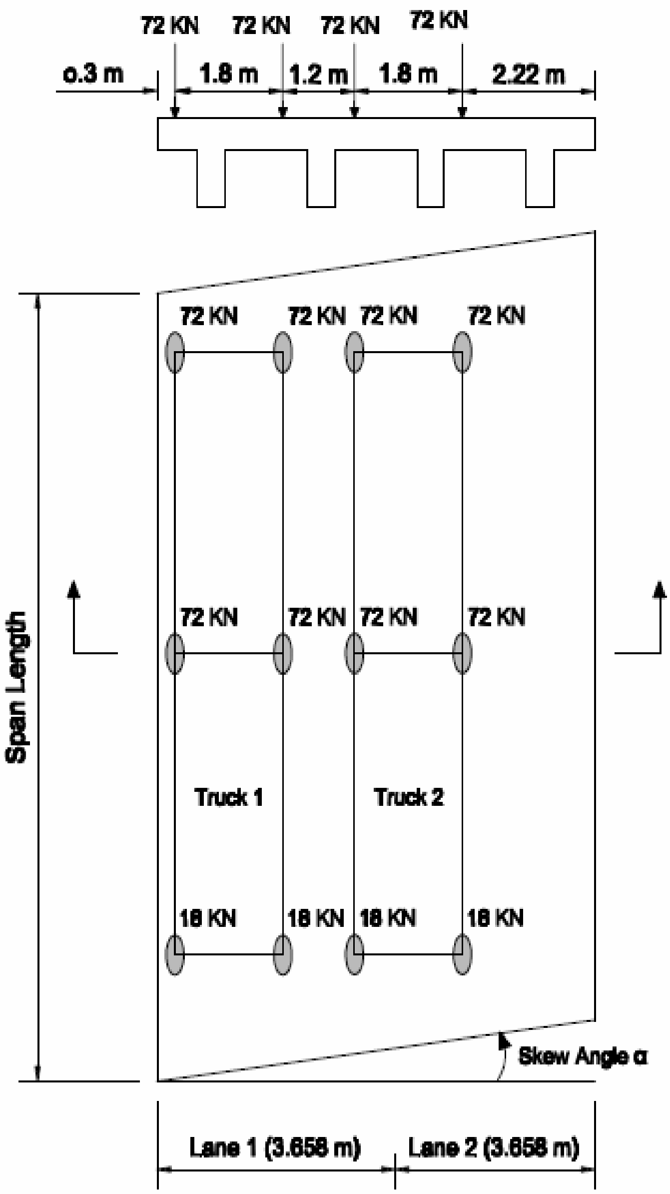

Figure 5-. Typical two-lane skewed bridge with edge truck loading

5. FINITE ELEMENT ANALYSIS

The general FEA program, STAADIII ver. 21 [6], was used to generate the three-dimensional (3D) finite element models. This study considered all elements to be linearly elastic and the analysis assumed small deformations and deflections STAAD III was used to generate nodes, elements and 3D mesh for the investigated bridge decks models.

The concrete slabs were modeled using shell element with 6° of freedom at each node, rectangular shell element with size of 0.4 x 0.915m and thickness equal 0.21m for strait bridge deck models and parallelogram shell element with size 0.4 x 0.915m and thickness equal 0.21m for skewed bridge deck models as shown in Figure-6.

The concrete longitudinal T-beams and ends diaphragms were modeled using line element with 6° of freedom of each node, these elements were assumed rectangular in shape with size different according to the span lengths as shown in Table-3. Hinges were assigned at one bearing location and rollers at the other for each four longitudinal beams in each model to simulate simple support condition, as shown in Figure-6.

The section properties for slab element (shell), beam and diaphragms elements (line) required for the analysis will be automatically calculated by STAADIII [6] program.

The material properties used in modeling the bridge decks was normal - strength reinforced concrete. The compressive strength (f_c') = 35 Mpa, the modules of elasticity (E_c) = 4700 $\sqrt{fc}$ ' = 27805.57 Mpa, the Poisson's ratio (ν) = 0.2. These values are in compliance with AASHTO [1] and ACI [7].

Two AASHTO HS-20 truck wheel loads were defined and applied by moving with an increment equal 0.4m on each models [6]. This procedure will simulate the movement of a two trucks in a specified direction on the deck models. The position of the two truck with the respect to decks were illustrates in Figure-5 as mentioned in section 4.

Table-3. Dimensions of longitudinal beams and ends diaphragms.

Span (m)	**Longitudinal beams**			**Ends diaphragms**		
	Shape	**Width** (m)	**Depth** (m)	**Shape**	**Width** (m)	**Depth** (m)
12	Rectangular	0.4	0.9	Rectangular	0.3	0.9
16	Rectangular	0.4	1.12	Rectangular	0.3	1.12
20	Rectangular	0.4	1.4	Rectangular	0.3	1.4
24	Rectangular	0.4	1.68	Rectangular	0.3	1.68

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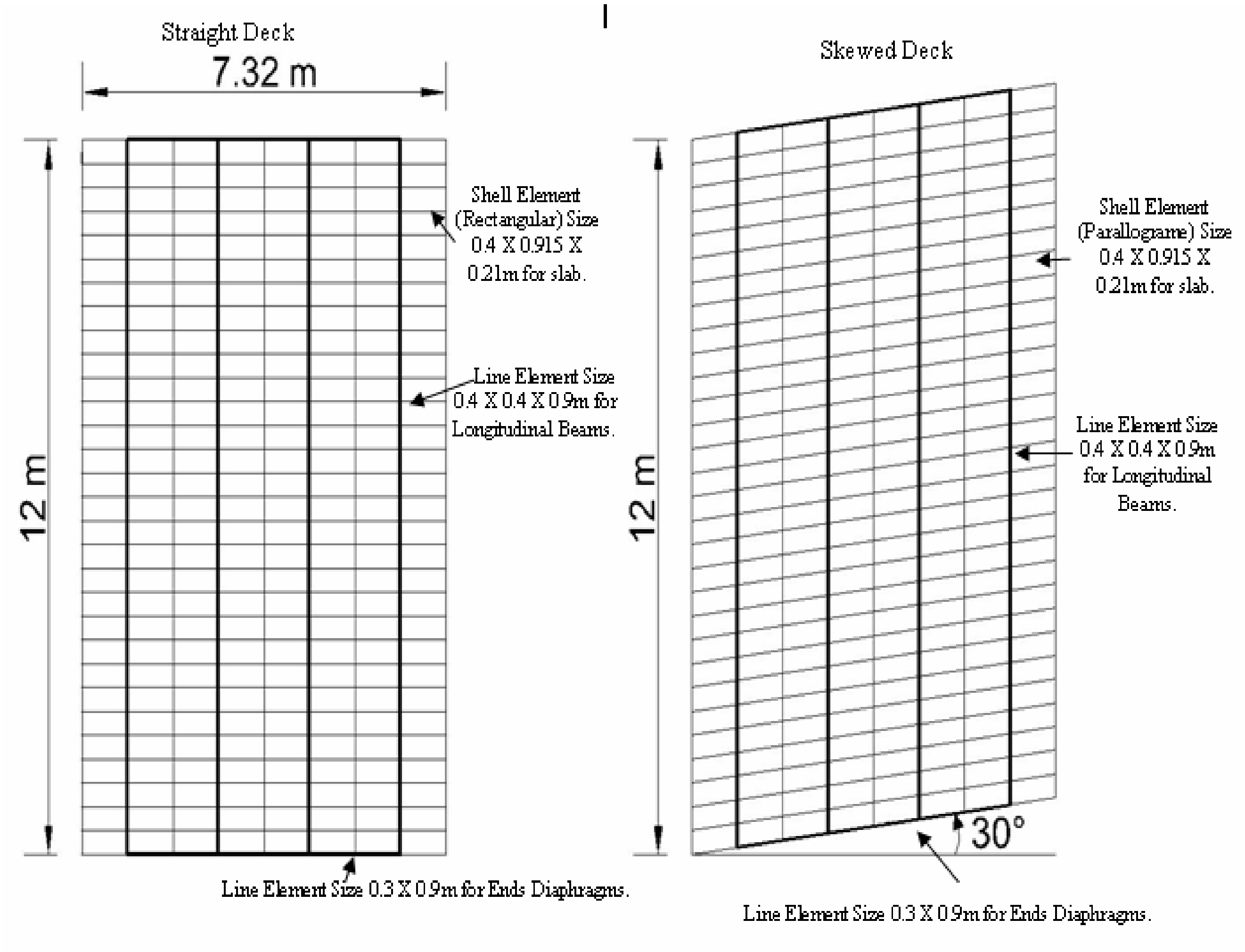

Figure-6. Typical finite element model for 12m span lengths.

6. RESULTS AND DISCUSSIONS

The FEA results were obtained and reported in terms of the maximums bending moment, shear, torsion, deflection and support reactions in longitudinal beams in the bridge deck models due to the applied live load (two HS-20 truck wheel loads) as referred before in section 4 and 5. The results of straight and skewed models are listed in Tables 4 to 8.

The effects of skewness of T-Beam deck models on the maximums live load bending moments, shear, torsions, deflections and supports reactions were also evaluated. Thus, the finite element results for skewed models with skew angles 15°, 30° and 45° are compared to their corresponding FEA values for straight bridges (skew angle = 0°). The FEA bending moments are presented in the form of the ratio Mα/M0, where Mα is the maximum FEA moment in the T-beam for given skew angle, α are 15°, 30° and 45°, and M0 is the FEA moment for nonskewed bridges (0° skewness). Similarly, the ratio Shα/Sh0,Tα/To, Δα/Δ0 and SPα/SP0 were calculated from the FEA shear, torsion, deflection and support reactions results, respectively as shown in Figures 7 to 11.

Table (4): Max. Live Bending Moment in Longitudinal T- Beams.

Span (m)	Skew angle	Beam No.1 (kN.m)	Beam No.2 (kN.m)	Beam No.3 (kN.m)	Beam No.4 (kN.m)
12	0°	344.38	314.22	255.03	190.42
	15°	342.53	307.18	248.31	186.82
	30°	326.98	283.83	228.03	173.88
	45°	292.96	240.3	186.59	144.46
16	0°	540.87	492.04	406.98	314.52
	15°	537.51	484.1	400.83	310.39
	30°	520.67	459.95	378.81	295.75
	45°	476.02	407.24	328.53	262.26
20	0°	745.12	676.18	559.8	430.79
	15°	740.37	667.2	554.83	427.43
	30°	723.25	647.19	534.28	415.73
	45°	683.47	596.33	487.43	385.68
24	0°	949.17	860.05	711.69	544.26
	15°	942.69	849.63	707.59	541.54
	30°	929.19	833.95	688.03	532.14
	45°	890.93	783.49	646.46	507.08

Table (5): Max Live load Shear in Longitudinal.

Span (m)	Skew angle	Beam No.1 (kN)	Beam No.1 (kN)	Beam No.1 (kN)	Beam No.1 (kN)
12	0°	144.61	143.43	106.02	48.66
	15°	152.02	131	100.26	51.35
	30°	152.61	116.23	83.6	55.98
	45°	150.66	108.56	68.23	62.97
16	0°	156.48	154.24	115.39	59.06
	15°	167.68	139.65	104.59	60.42
	30°	171.84	133.52	101.57	63.69
	45°	182.57	120.58	110.19	68.39
20	0°	167.61	165.18	122.61	64.32
	15°	177.58	151.17	113.25	67.29
	30°	183.48	136.53	113.6	70.28
	45°	189.39	130.49	116.51	73.31
24	0°	175.28	173.2	127.57	67.63
	15°	184.26	159.6	119.25	70.41
	30°	190.78	146.65	121.34	73.66
	45°	193.12	137.22	125.22	78.94

Table (6): Max. live load Torsion in longitudinal T-Beams.

Span (m)	Skew angle	Beam No.1 (kN/m)	Beam No.1 (kN/m)	Beam No.1 (kN/m)	Beam No.1 (kN/m)
12	0°	14.04	20.36	28.8	22.88
	15°	27.29	28.93	33.28	24.91
	30°	42.88	39.37	37.77	28.3
	45°	56.68	49.96	40.84	30.72
16	0°	20.46	28.13	37.69	31.8
	15°	34.99	37.06	41.95	33.2
	30°	52.74	48.36	47.28	37.14
	45°	73.07	60.39	52.71	41.63
20	0°	24.12	32.55	42.66	43.94
	15°	37.6	40.10	45.83	45.6
	30°	54.6	50.14	50.41	47.84
	45°	75.32	62.53	56.94	50.98
24	0°	26.94	35.53	45.76	41.39
	15°	39.19	41.94	48.09	41.8
	30°	54.89	50.65	51.77	42.89
	45°	75.36	62.38	58	47.78

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Table-7. Max. live load deflection in longitudinal T- Beam.

Span (m)	**Skew angle**	**Beam No. 1** (cm)	**Beam No. 2** (cm)	**Beam No. 3** (cm)	**Beam No. 4** (cm)
12	0°	- 0.956	-0.86	- 0.709	- 0.547
	15°	- 0.936	- 0.838	- 0.691	- 0.53
	30°	- 0.870	- 0.765	- 0.626	- 0.485
	45°	- 0.74	- 0.618	-0.48	-0.37
16	0°	- 1.357	- 1.22	- 1.025	- 0.816
	15°	- 1.33	-1.201	-1.00	-0.803
	30°	-1.267	-1.127	-0.942	-0.756
	45°	-1.12	-0.966	-0.798	-0.648
20	0°	-1.48	-1.31	-1.1	-0.88
	15°	-1.45	-1.3	-1.09	-0.874
	30°	-1.402	-1.249	-1.04	-0.843
	45°	-1.29	-1.12	-0.939	-0.766
24	0°	-1.527	-1.369	-1.152	-0.919
	15°	-1.51	-1.358	-1.143	-0.913
	30°	-1.48	-1.319	-1.109	-0.893
	45°	-1.395	-1.225	-1.02	-0.839

Table-8. Max. live load support reactions in longitudinal T-Beam.

Span (m)	**Skew angle**	**Beam No. 1** (kN)	**Beam No. 2** (kN)	**Beam No. 3** (kN)	**Beam No. 4** (kN)
12	0°	166.47	173.5	129.92	27.47
	15°	187.22	136.84	102.88	21.9
	30°	207.43	106.43	75.2	13.71
	45°	234.54	63.05	46.08	-4.03
16	0°	182.33	184.55	146.37	30.01
	15°	200.56	152.44	116.35	26.46
	30°	219.99	129.61	90.39	22.27
	45°	252.73	85.33	88.86	12.28
20	0°	190.73	192.63	145.64	31.67
	15°	207.98	161.14	122.86	31.068
	30°	220.43	139.46	99.78	27.2
	45°	249.36	113.52	76.84	21.44
24	0°	196.12	198.23	148.64	32.99
	15°	208.45	173.52	128.95	32.79
	30°	220.07	153.93	106.3	33.72
	45°	244.61	133.82	85.35	28.26

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6.1 Maximum live load bending moments in longitude T-Beams

General behavior indicate that maximum bending moments in T-beam bridge decks for skewed bridges compared to that of straight bridges decreases with increase of skew angle for all considered span lengths (12,16, 20 and 24m) as shown in Figure-7.

The decrement in maximum bending moment in longitudinal T-beams are summarized as follows: The ratio Mα/M0 is ranging from 0.9 to 0.99 for the four beams in the decks models at skew angles 15° and 30° for spans lengths (12, 16, 20 and 24m), while the ratio Mα/M0 has different values for bridge decks with skew angle equal 45° for each considered span lengths as follows: The ratio Mα/M0 is ranging from 0.73 to 0.85 for span length =12m; 0.8 to 0.88 for span length = 16m; 0.87 to 0.91 for span length =20m and 0.9 to 0.93 for span length =24m for the four beams.

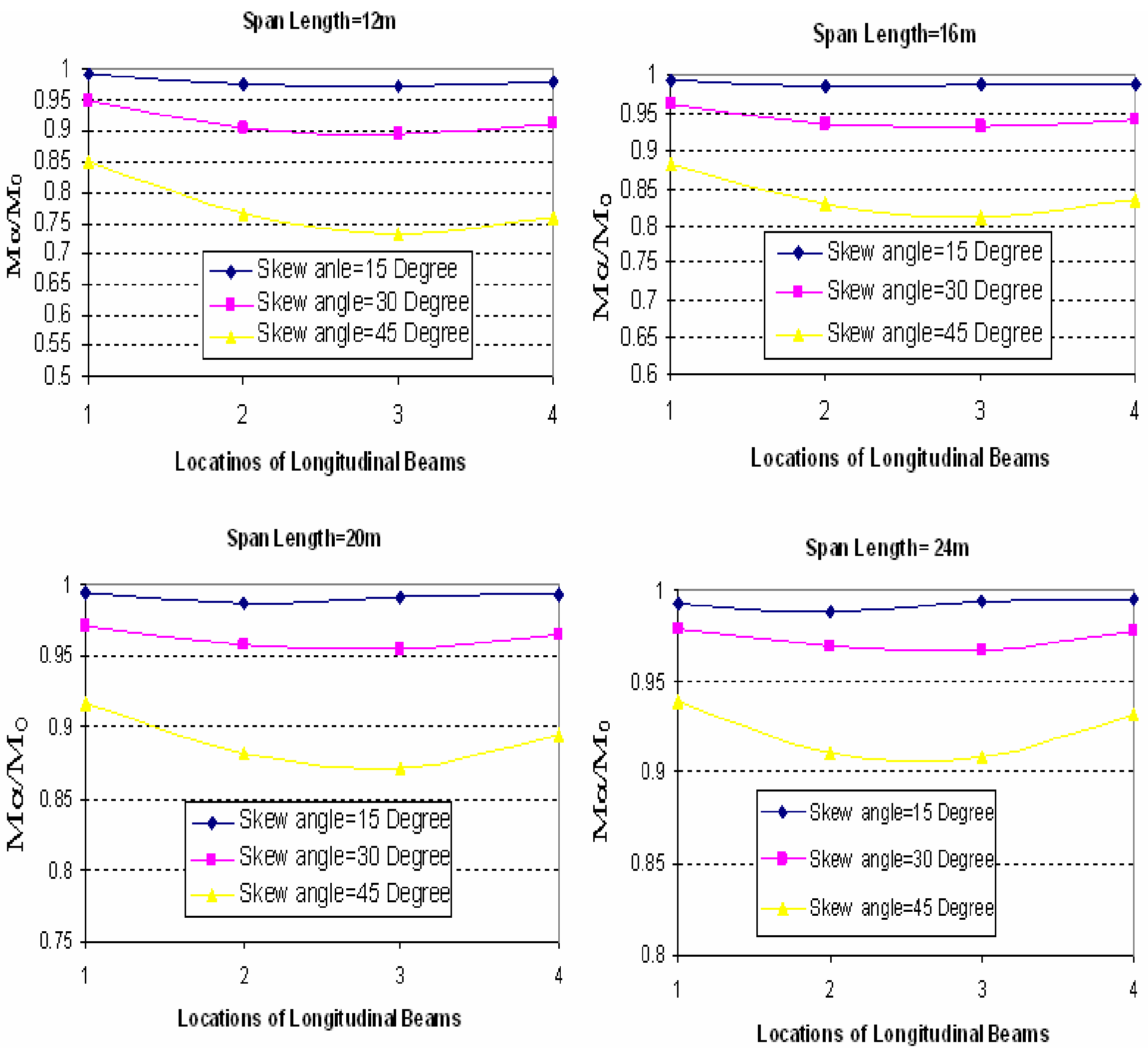

Figure-7. FEA maximum live load bending moments in longitudinal T-Beams -ratio Mα/M0.

6.2 Maximum live load shear in longitudinal T-Beams

General behavior indicate that maximum shear in T-beams bridge decks for skewed bridges shows a wide variation compared to that of straight bridges. The exterior beams (B.1 and B.4) have shear values increases with skew angles and the interior beams (B.2 and B.3) decrease with skew angle for considered span lengths (12, 16, 20 and 24m) as shown in Figure-8.

The variations in the results of maximum shear for skewed T-beam bridge decks are summarized as follows: The ratio Shα/Sh0 is ranging from 1.04 to 1.166 for beam No.1 and 1.05 to 1.29 for beam No. 4 in the deck models for skew angle up to 45° for all spans, while the ratio Shα/Sh0 for beams No. (2 and 3) is ranging is from 0.9 to 0.94 for skew angle 15°; 0.78 to 0.95 for skew angle 30° and 0.64 to 0.98 for skew angle 45° for considered span lengths (12, 16, 20 and 24m).

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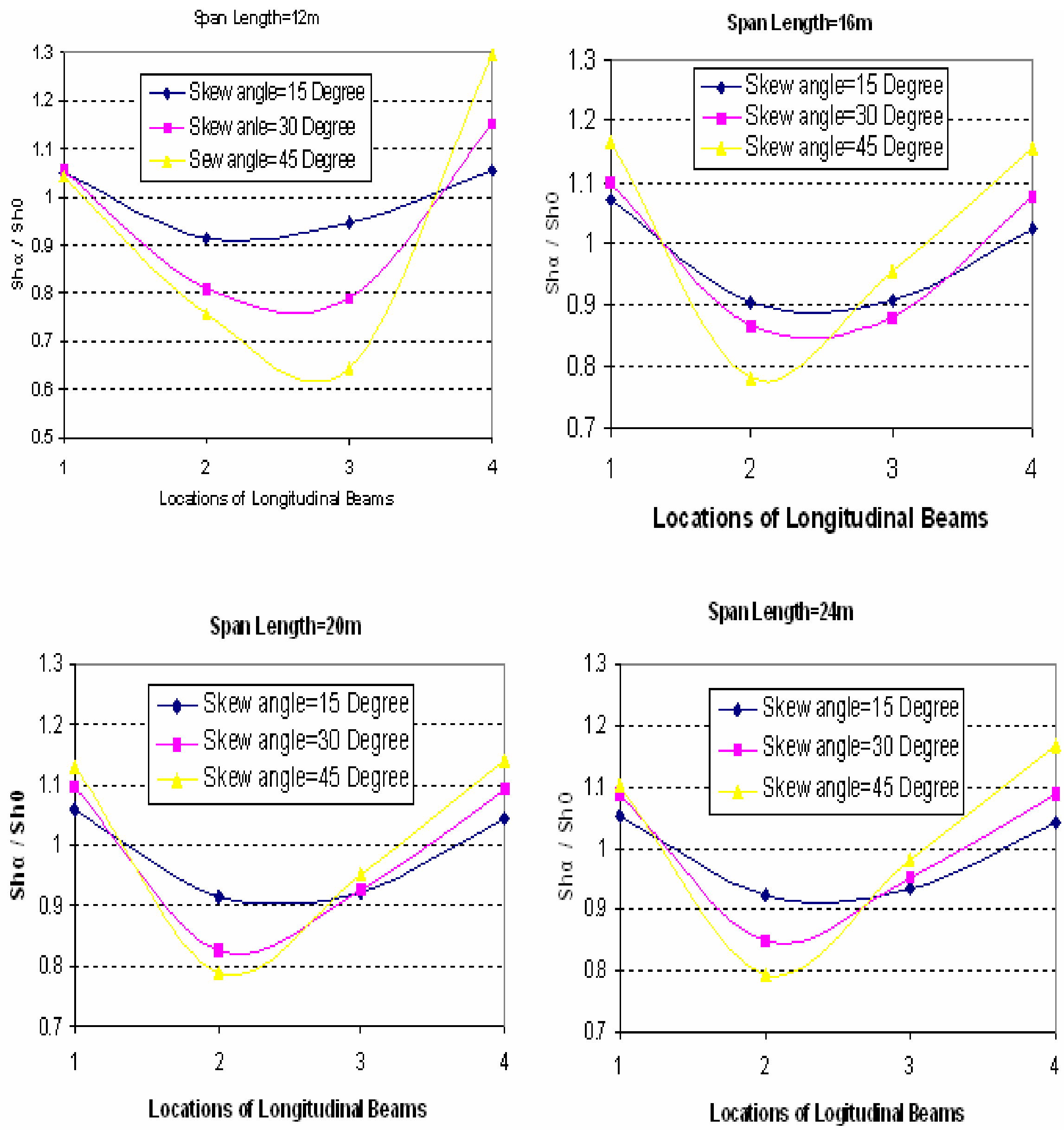

Figure-8. FEA maximum live load shear in longitudinal T-Beams -ratio Shα/Sh0.

6.3 Maximum live load torsion in longitudinal T-beams

General behavior indicate that maximum torsion in T-beam bridge decks for skewed bridges compared to that of straight bridges increases with increase of skew angle for considered span lengths (12, 16, 20 and 24m) as shown in Figure-9. The increments in the results of maximum torsion for skewed T-beam bridge decks, are summarized as follows: The ratio Tα/To for beam No.1 are 1.94 ,1.71 ,1.55 and 1.45 at skew angle 15°; 3.05, 2.57, 2.26 and 2.03 at skew angle 30°; 4.03, 3.57, 3.12 and 2.79 at skew angle 45° for spans lengths 12, 16, 20 and 24m, respectively; while for beams No. 2 and 3 and beam No. 4, the ratio Tα/To is ranging from 1 to 1.42 for skew angle 15°; 1 to 1.93 for skew angle 30°; 2.4 to 1.75 for skew angle 45° for considered span lengths (12, 16, 20, and 24m).

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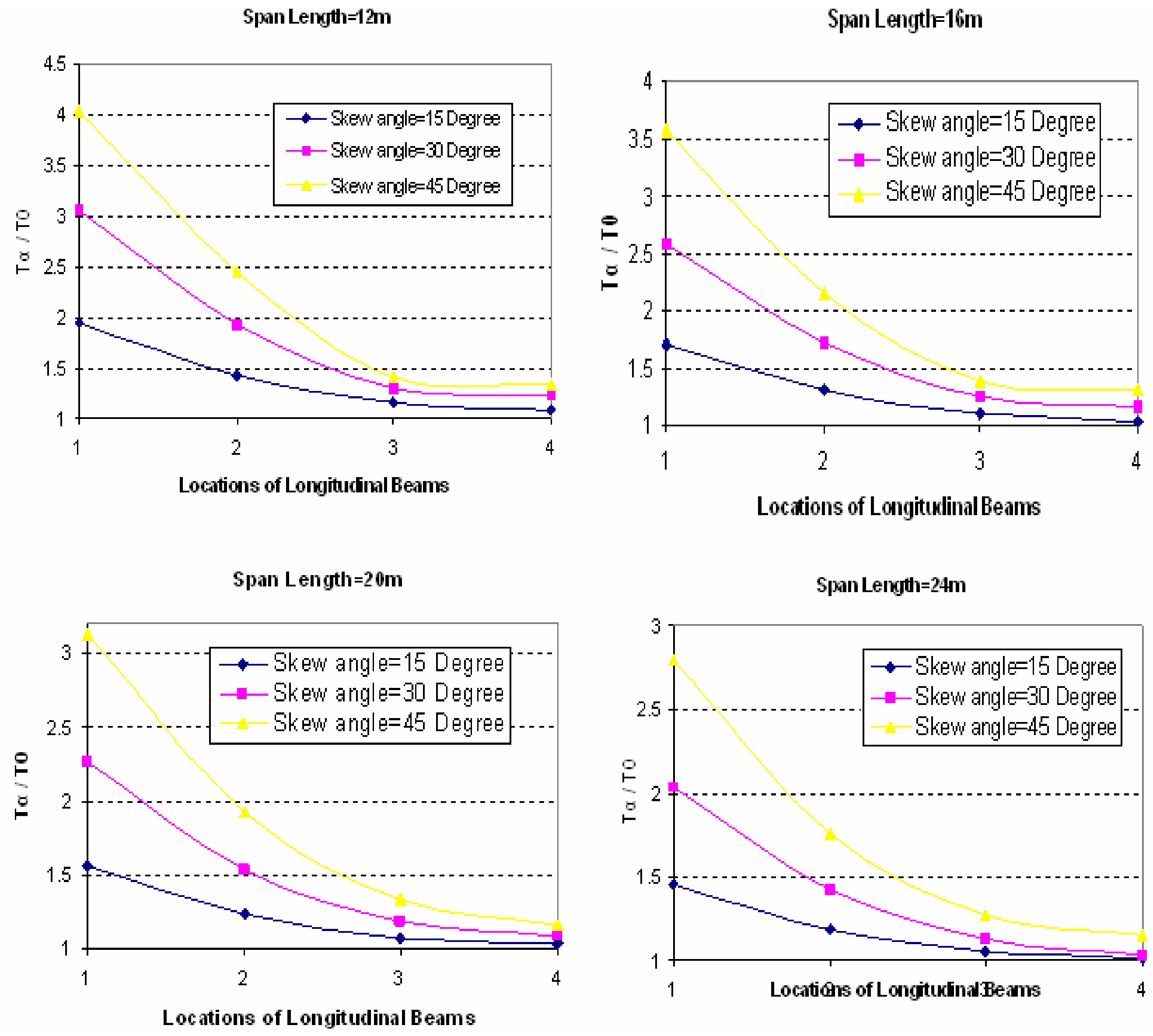

Figure-9. FEA maximum live load torsion in longitudinal T-Beams -ratio Tα/T0.

6.4 Maximum live load deflections in longitudinal T-Beams

General behavior indicate that maximum deflections in T-beam bridge decks for skewed bridges compared to that of straight bridges decreases with increase of skew angle for all considered span lengths (12, 16, 20 and 24m) as shown in Figure-10.

The decrement in max deflections in T-beams are summarized as follows: The ratio $\Delta\alpha/\Delta 0$ is ranging from 0.82 to 0.992 at skew angles 15° and 30° for the four beams in the deck models for considered span lengths (12, 16, 20 and 24m), while the ratio $\Delta\alpha/\Delta 0$ is ranging from 0.658 to 0.913 at skew angle 45° for the four beams in the deck models for considered span lengths (12, 16, 20 and 24m).

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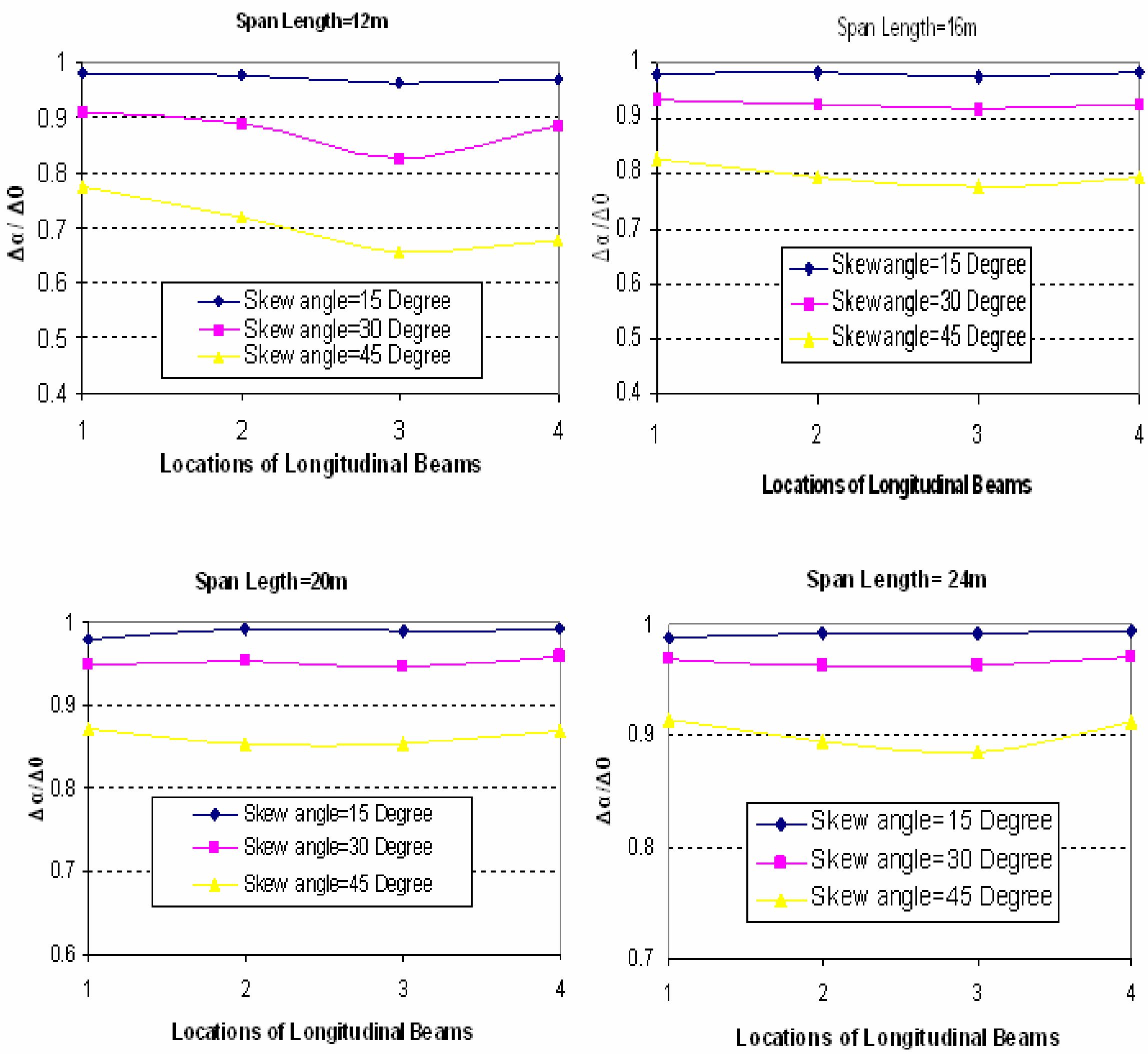

Figure-10. FEA Max. live load deflections in longitudinal T-Beams -ratio Δα/Δ0.

6.5 Maximum live load support reactions in longitudinal T-Beams.

General behavior indicates that max. Support reactions in T-beam bridge decks for skewed bridges shows a wide variation compared to that of straight bridges. Beam No.1 has support reactions values increases with skew angles and Beam No. 2, 3 and 4 have support reactions values decrease with skew angles for considered span lengths (12, 16, 20 and 24m) as shown in Figure-11.

The variations in the results of maximum support reactions for skewed T-beam Bridge decks are summarized as follows: The ratio SPα/SP0 for beam No.1 is ranging from 1.06 to 1.4 at skew angles 15°, 30° and 45° for considered span lengths (12, 16, 20 and 24m), while the ratio SPα/SP0 for beams No. 2, 3 and 4 are 0.788 to 0.991 at skew angle 15°; 0.499 to 0.829 at skew angle 30° and - 0.146 to 0.856 at skew angle 45° for considered span lengths (12, 16, 20 and 24 m).

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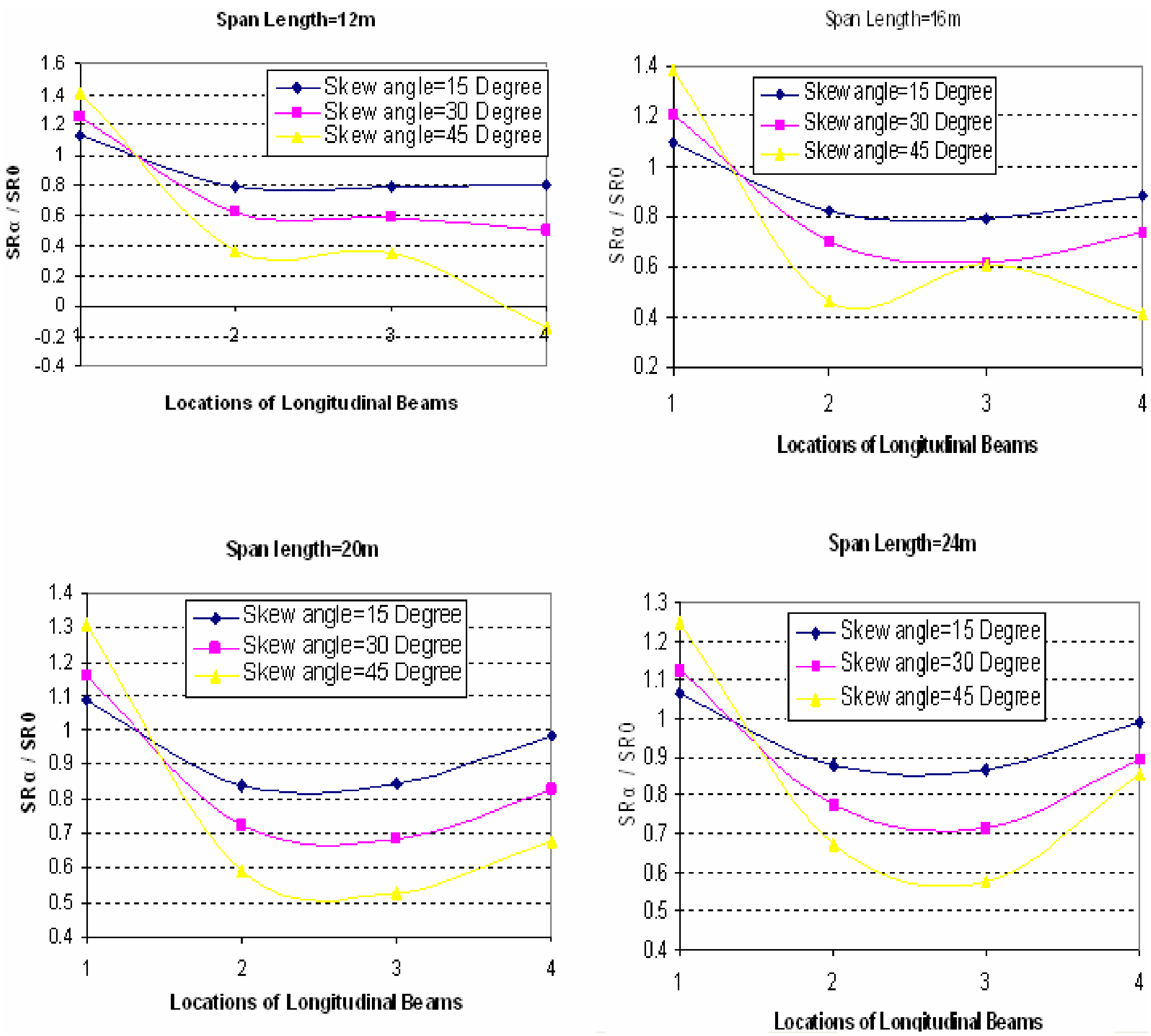

Figure-11. FEA max. support reactions in longitudinal T-Beams -ratio SRα/SR0.

7. CONCLUSIONS

The effects of skew angle in single span two lane reinforced concrete T-beam bridge deck were investigated and the FEA are presented in this paper. The study involved varying the span lengths (12, 16, 20 and 24m) and skew angles (0°, 15°, 30° and 45°).

The results were compared with straight bridges to clearly understand the effect of skewness on the T-beam bridge decks.

From the results of FEA and comparison of skew bridges with straight bridges for considered span lengths (12, 16, 20 and 24m), the following concluding remarks are noticed:

a) The max. Live load bending moment in T-beams Bridge decks decrease for skewed bridges. The decrements at skew angle 15° and 30° is ranging from 1% to 10% for span lengths (12, 16, 20 and 24m), while the decrement at skew angle 45° is different for each considered spans, the decrement is ranging from 15% to 27% for span length=12m; 12% to 20% for span =16m; 9% to 13% for span length =20m and 7% to 10% for span length= 24m.

b) The max. Live load deflections in T-beams bridge decks decrease for skewed bridges. The decrements at skew angles 15° and 30° is ranging from 0.8% to 18% and 8.7% to 34.2% at skew angle 45° for all considered span lengths (12, 16, 20 and 24m).

c) The max. Live load shear in T- beams bridge decks increase for exterior beams (1and 4) and decreases for interior beams No. (2 and 3) for skewed bridges. The increment for beam No.1 is ranging from 4% to 16.6 % and from 5% to 29% for beam No. 4 at skew angle 15°, 30° and 45° while the decrements for beams No.2 and 3 is ranging from 6% to 10% at skew angle 15°; 5% to 22% at skew angle 30° and 2% to 36% at skew angle 45° for all considered span lengths (12, 16, 20 and 24m).

d) The maximum Live load torsions in T-beams bridge decks increases for skewed bridges. The increment for beam No. 1 is ranging from 45% to 94 % at skew angle 15°; 100% to 300% at skew angle 30° and 312% to 400% at skew angle 45° for all considered span lengths, while for beams No.2,3 and 4 the increments is ranging from 0% to 42% at skew angle 15°; 0 to

93% at skew angle 30° and 75% to 140% at skew angle 45° for considered span lengths (12, 16, 20 and 24m).

e) The max. Live load support reactions in T- beams bridge decks increases for beam No.1 and decreases for beams No.2, 3 and 4 for skewed bridges. The increment for beam No.1 is ranging from 6% to 40% at skew angles 15°, 30° and 45° for all considered span lengths (12, 16, 20 and 24m), while the decrement, in beams 2, 3 and 4 is ranging from 0.9 % to 22% at skew angle 15° from 17.1% to 50% at skew angle 30°and from - 14.6 % to 14.4 % at skew angle 45° for all considered span lengths (12, 16, 20 and 24m).

In general, this research disagreement with the AASHTO [2] standard specifications as well as the LRFD [3] in recommending that bridge with skew angle less than or equal 20° be designed as straight (non skewed) bridges, since max. Live load shear, torsion and supports reactions in some T-beams increases for skewed bridges as referred above. It is recommended that engineers are better to perform three - dimensional finite - element analysis for skewed T-beam bridge decks.

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