Thermal Loads Effect on Response of One-Story Reinforced Concrete Frame Buildings in UAE

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Abstract. In this paper the effect of temperature change (thermal load) on one-story reinforced concrete frame buildings allocated in the UAE is studied. Sixty eight finite element models with different story heights and slab lengths were developed in ETABS to carry out this study. The effect of temperature change with the variation of story height, slab length and support condition on the lateral displacement and horizontal reactions was studied in this paper. The thermal load results for the fixed support models showed that for different buildings with the same column heights, the external columns' displacements and reactions increased considerably with increasing the slab length. Comparing the horizontal reaction results –due to thermal loads- of the two modeled building heights (3 m and 6 m) showed that the 6 m models have lower reactions at external columns but larger top displacements. The comparison between the lateral load results for fixed and hinged support conditions showed that models with fixed support conditions had lower lateral displacement but higher horizontal reactions due to thermal loads. The effect of the support condition on the lateral displacement was larger for longer slab lengths whereas its effect on the horizontal reaction was larger for smaller slab lengths. The support conditions showed to have larger effect on the shorter column models.

1 Introduction

The UAE is known for its high temperatures especially during the summer period. This high temperature along with the frequent fluctuation in the daily and seasonal temperatures imposes extra loads on structures. The Abu Dhabi International Building Code (2013) (ADIBC) considers temperature loads as one of the main important loads to be verified and analyzed in reinforced concrete structures in the UAE [1]. Seasonal changes in temperature causes overall structural deformation, displacements, in addition to differential stresses in concrete elements. It has to be considered for building serviceability conditions and to eliminate the additional thermal cracks [2]. When studying the effect of temperature change

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on reinforced concrete buildings two important factors should be considered: the nature of the temperature change and the fundamental materials properties of concrete.

In service, thermal effects are related to the difference between the highest temperature during summer and the lowest temperature during winter [2]. The highest temperature registered in the UAE was found to be 50°C (in the western region); whereas the lowest registered temperature was found to be 10°C. The magnitude of the forces developed and the amount of displacements caused by temperature changes are directly related to building length [2]. Contraction and expansion joints are means used to limit the magnitude of forces, displacements and cracking induced by temperature [3]. A common practice in the UAE is that expansion joints spacing shouldn't be more than 120ft (36.6m) considering recognized committees recommendations [1,2,4], when the spacing exceeds 450ft (46m), then a special design including a thermal study has to be performed [2,5].

2 ETABS models input data and conditions

2.1 Concrete properties

The thermal coefficient of concrete is usually affected by many factors such as the type of aggregate, moisture content, mix properties, cement type and age of concrete. For ordinary thermal stresses calculations a thermal coefficient value of 10x10-6/°C can be used when the type of aggregate and concrete degree of saturation are unknown [2, 6]. Accordingly this value was implemented in the used ETABS models (Fig. 1). The rest of the concrete properties are presented in Table 1.

Table 1. Concrete properties used in the model.

Concrete Property	Value
Concrete compressive strength (<i>f_c'</i>)	40 N/mm ²
Modulus of elasticity (<i>E</i>)	30000 MPa
Poisson ratio	0.2
Mass per unit volume	2400 kg/m ³

Fig. 1. Typical model: a) Top view slab and b) 3D view.

2.2 ETABS model geometry

Sixty eight ETABS one-story reinforce concrete frame building models were generated in this study (Fig. 1). These models were divided into two sets: fixed support reaction and

hinged support reaction and each set consists of two model groups: the first group with column heights of 3.00 m and the second group with column heights of 6 m. Each group consists of 17 different ETABS models. The difference between these models is the concrete slab length which was increased from 50 m to 400 m by increments of 10 m. These models were generated to verify the effect of temperature change with variation in column height, slab length and support conditions on the lateral displacement and horizontal reactions in one-story reinforced concrete frame buildings in UAE. The rest of the model geometry was taken as follows:

- i) Slab thickness = 300mm
- ii) Columns size = 800 x 800 mm²
- iii) Thermal load = 40 °C
- iv) Slab width = 50 m.

Thermal loads (40 C°) were assigned as uniform temperature change at all slab shells elements at upper slab level.

3 Results and analysis

In this section the results of the thermal study conducted on the sixty eight reinforced concrete frame structure models are presented. The results from the first set of models with fixed support conditions were used to study the effect of temperature change with variation in column height and slab length on the lateral displacement and horizontal reactions in one-story reinforced concrete frame buildings in UAE. The results from the second set of models with hinged support conditions were compared to the results of the first set of models to study the influence of the support conditions on the temperature change results.

3.1 Effect of thermal load

For the first set of models (with fixed support) the change in the horizontal reactions and the top deflection at the external columns A1, B1, C1, D1, E1 and F1 with different slab lengths under thermal load are shown in Fig. 2 and Fig. 3 for the 3 m and 6 m high structures, respectively. Due to symmetry in the analyzed models these columns will have the same results as those for columns A11, B11, C11, D11, E11 and F11, respectively. All models were found to be safe under dead and live loads.

These thermal load results show that for the same building the displacements at external columns have different but close values. The results also show that for different buildings with the same column heights, the external columns' displacements increases considerably with increasing the slab length. The external column displacements for 400 m slab was about three times that for the 50 m slab length for the 3 m high column models and about five times for that in the 6 m high column modes. The maximum allowable lateral deflection in columns is (height/180) to avoid damage to external walls [3]. This limit is 16.7 mm and 33.3 mm for the 3 m and 6 m high columns, respectively. The model results showed that this limit was exceeded for slabs with length more than 100 m for the 3 m high column models and for slabs with length more than 200 m for those of the 6 m high column models.

For the same building (in the first model set) the thermal load results showed that the horizontal reactions (parallel to the slab length) at external columns' supports have different but close values. For different buildings with the same column height, the external columns reactions at supports increased considerably with the increase of the slab length. This has a big impact on these columns and its related footing design. The study results showed that the reactions for the 400m long slab was about three times that for 50 m long slab for the 3 m high column models and about nine times for the 6 m high column models. Comparing

the results of the two modeled building heights (3 m and 6 m) show that the 6 m models have lower reactions at external columns but larger top displacements due to the thermal loading.

Fig. 2. Results of thermal study at external columns for 3 m height models and different slab length: a) Reaction and b) Horizontal displacement.

Fig. 3. Results of thermal study at external columns for 6 m height models and different slab length: a) Reaction and b) Lateral displacement.

3.2 Effect of support conditions on the thermal response

To study the effect of support type on the displacement and reactions of external columns under thermal load a second set of thirty four new models were created. This set of models had the same properties as the first set of models except that the second set had hinged support condition instead of fixed support condition. The displacements under thermal load results for both sets of models are shown in Table 2 and Table 3 for models with column heights (3 m) and (6 m), respectively. The comparison between the results of both sets of models showed that the displacement for the models with hinged support had higher values than that for the fixed support. This increase in the value of displacement increased with the increase of the slab length for each column height. When comparing the results for the 3m high columns models and the 6 m high column models it was found that the support condition had a larger effect on the shorter column length. The ratio of the lateral displacement for the fixed support condition to the hinged support condition for the 6 m column height is larger than 75% for all slab lengths. For the 3 m high column models the

ratio of the lateral displacement for the fixed support conditions to the hinged support condition for slab lengths lesser than 160 m were more than 75%. This ratio decreases with the increase of the slab length with a reduction reaching 45% for slab length of 400 m.

Table 2. Lateral deformation for column height (3 m) with fixed and hinged supports.

Slab Length (m)	Fixed columns conditions			Hinged columns conditions		
	A1 & F1 [mm]	B1 & E1 [mm]	C1 & D1 [mm]	A1 & F1 [mm]	B1 & E1 [mm]	C1 & D1 [mm]
50	9.1397	9.258	9.2946	9.8593	9.8544	9.8559
60	10.6902	10.9077	10.9556	11.8096	11.8055	11.8065
80	13.5291	13.9285	13.998	15.6769	15.674	15.6736
100	15.9955	16.5529	16.6606	19.4882	19.4863	19.4845
120	18.1666	18.7634	18.8693	23.1548	23.1542	23.1516
140	19.8894	20.5792	20.6982	26.7737	26.7737	26.7699
160	21.2884	22.0537	22.1834	30.2894	30.286	30.2849
180	22.4085	23.2343	23.3726	33.6918	33.693	33.6867
200	23.2953	24.169	24.314	36.9725	36.9742	36.9668
220	23.9912	24.9024	25.0528	40.1246	40.127	40.1184
240	24.5334	25.4739	25.6284	43.143	43.1459	43.1363
260	24.9536	25.9167	26.0744	46.0239	46.0273	46.0166
280	25.2778	26.2585	26.4186	48.765	48.7688	48.7572
300	25.5271	26.5213	26.6833	51.3654	51.3696	51.3571
340	25.8649	26.8773	27.0419	56.1462	56.1513	56.1371
380	26.0624	27.0855	27.2516	60.3813	60.3872	60.3715
400	26.1277	27.1543	27.3209	62.3026	62.3088	62.2924

Table 3. Lateral deformation for column height (6 m) with fixed and hinged supports.

Slab Length (m)	Fixed columns conditions			Hinged columns conditions		
	A1 & F1 [mm]	B1 & E1 [mm]	C1 & D1 [mm]	A1 & F1 [mm]	B1 & E1 [mm]	C1 & D1 [mm]
50	9.7842	9.8001	9.8057	9.9	9.9	9.9
60	11.691	11.7247	11.7324	11.9	11.9	11.9
80	15.4494	15.5183	15.5299	15.8	15.8	15.8
100	19.1189	19.2221	19.2375	19.7	19.7	19.7
120	22.6826	22.7991	22.8186	23.6	23.6	23.6
140	26.1135	26.2569	26.2801	27.5	27.5	27.5
160	29.4063	29.5755	29.6022	31.4	31.4	31.4
180	32.5508	32.7447	32.7747	35.2	35.2	35.2
200	35.5395	35.7569	35.79	39	39	39
220	38.3674	38.607	38.6431	42.7	42.7	42.7
240	41.0318	41.2923	41.3312	46.5	46.5	46.5
260	43.532	43.8121	43.8538	50.1	50.2	50.1
280	45.8694	46.1679	46.212	53.8	53.8	53.8
300	48.047	48.3625	48.4089	57.4	57.4	57.4
340	51.9406	52.2867	52.3373	64.4	64.4	64.4
380	55.2592	55.6313	55.6854	71.2	71.3	71.2
400	56.7203	57.1039	57.1595	74.6	74.6	74.6

The horizontal reaction under thermal load results for both sets of models are shown in Table 4 and Table 5 for models with column heights (3 m) and (6 m), respectively. The comparison between the horizontal reaction results of both sets of models showed that the reaction for the models with hinged support had lower values than that for the fixed

support. The effect of support condition was larger on models with smaller slab lengths for both column heights. The column height was found to be inversely proportional to horizontal reaction values. It is clear that models with 3 m story height and fixed columns supports have the most critical reaction values. Horizontal reaction related to column height 3 m is three to five times bigger than reactions related to columns with height 6 m. Fixed columns reactions for models with 3 m column height are around 15 times the hinged column reaction for model with 3 m column height and slab length 50 m. This ratio decreased for models with longer slabs where, this ratio is around 6 for models with slab length of 400 m.

Table 4. Horizontal reactions for column height (3m) with fixed and hinged supports.

Slab Length (m)	Fixed columns conditions			Hinged columns conditions		
	A1 & F1 [kN]	B1 & E1 [kN]	C1 & D1 [kN]	A1 & F1 [kN]	B1 & E1 [kN]	C1 & D1 [kN]
50	1060.24	1146.31	1151.28	37.38	74.31	74.56
60	1240.91	1352.62	1358.96	45.19	90.16	90.36
80	1571.72	1730.42	1739.33	60.68	121.58	121.68
100	1859.13	2058.64	2069.73	75.95	152.55	152.55
120	2147.02	2393.91	2408.15	111.88	217.19	217.41
140	2351.02	2627.11	2642.98	129.61	252.36	252.49
160	2516.67	2816.47	2833.66	146.83	286.52	286.56
180	2649.3	2968.09	2986.34	163.5	319.58	319.54
200	2754.31	3088.13	3107.21	179.57	351.46	351.33
220	2836.7	3182.32	3202.06	195.01	382.09	381.88
240	2900.9	3255.71	3275.96	209.8	411.42	411.14
260	2950.65	3312.58	3333.23	223.91	439.41	439.06
280	2989.04	3356.46	3377.42	237.34	466.05	465.63
300	3018.56	3390.22	3411.41	250.08	491.31	490.83
340	3058.56	3435.94	3457.45	273.5	537.77	537.17
380	3081.95	3462.67	3484.38	294.24	578.92	578.21
400	3089.68	3471.51	3493.27	303.66	597.59	596.83

Table 5. Horizontal reactions for column height (6m) with fixed and hinged supports.

Slab Length (m)	Fixed columns conditions			Hinged columns conditions		
	A1 & F1 [kN]	B1 & E1 [kN]	C1 & D1 [kN]	A1 & F1 [kN]	B1 & E1 [kN]	C1 & D1 [kN]
50	157.36	176.65	176.92	9.05	17.38	17.47
60	188.25	211.92	212.2	10.95	21.1	21.17
80	249.12	281.43	281.73	14.75	28.52	28.57
100	308.56	349.29	349.61	18.53	35.91	35.94
120	377.2	432.08	432.63	27.25	50.82	50.91
140	434.38	498.2	498.78	31.78	59.44	59.51
160	489.25	561.66	562.26	36.28	68.01	68.05
180	541.65	622.26	622.89	40.75	76.51	76.53
200	591.46	679.86	680.52	45.18	84.94	84.94
220	638.58	734.36	735.04	49.57	93.3	93.27
240	682.98	785.71	786.41	53.91	101.57	101.52
260	724.65	833.9	834.61	58.21	109.75	109.68
280	763.6	878.94	879.68	62.46	117.83	117.74
300	799.89	920.91	921.66	66.65	125.81	125.7
340	864.78	995.95	996.74	74.87	141.45	141.29
380	920.08	1059.9	1060.72	82.84	156.62	156.42
400	944.43	1088.06	1088.89	86.73	164.01	163.8

4 Conclusions

Throughout this research, sixty eight ETABS models of one-story reinforced concrete frame buildings were studied under thermal load from UAE registered values. These models were divided into two sets: fixed support reaction and hinged support reaction and each set consists of two model groups: the first group with column heights of 3 m and the second group with column heights of 6 m. Each group consists of 17 different ETABS models. The difference between these models is the concrete slab length which was increased from 50 m to 400 m by increments of 10 m. The findings of this research confirmed the considerable additional lateral deformations at slab level and horizontal forces at supports due to temperature loads. These deformations and reactions increases considerably with increasing the slab length. For a fixed support condition the horizontal displacements for 400 m slab was about three times that for the 50 m slab length for the 3 m high column models and about five times for that in the 6 m high column models. Whereas, the reactions for the 400 m long slab was about three times that for 50 m long slab for the 3 m high column models and about nine times for the 6 m high column models.

When comparing the thermal loads results of both fixed and hinged support conditions, the displacement for the models with hinged support condition had higher values than that for the fixed support condition. The ratios of the lateral displacement under thermal loads for the fixed support condition to the hinged support condition for all the 6 m column height models and 3 m column height models with slab lengths lesser than 160 m were larger than 75%. This ratio decreases with the increase of the slab length for the 3 m column height models with a reduction reaching 45% for slab length of 400 m. The comparison between the horizontal reaction results of both sets of models showed that the reaction for the models with hinged support had lower values than that for the fixed support. The effect of support condition was larger on models with smaller slab lengths and shorter column heights. Horizontal reaction related to column height 3m is three to five times bigger than reactions related to columns with height 6m. Fixed columns reactions for models with 3m height are around 15 times the hinged column reaction for model with 3m column height and slab length 50m. This ratio will be decreased for models with longer slabs where, this ratio will be around 6 for models with slab length of 400m.

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