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

Sabouni Reem1,*, and Sydnaoui Ikhlass2

1Civil Engineering Department Chair, Civil Engineering Department. ALHOSN University, Abu Dhabi, UAE
2Structural Engineer, Musanada, Abu Dhabi General Services Company, Abu Dhabi, UAE

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

* Corresponding author: r.arsabouni@alhosnu.ae

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (http://creativecommons.org/licenses/by/4.0/).
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.

| Concrete Property                  | Value       |
|------------------------------------|-------------|
| Concrete compressive strength ($f'_c$) | 40 N/mm²   |
| Modulus of elasticity ($E$)        | 30000 MPa   |
| Poisson ratio                      | 0.2         |
| Mass per unit volume               | 2400 kg/m³  |

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 ºC
iv) Slab width = 50 m.

Thermal loads (40 ºC) 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              | 13.5361      | 13.9285       | 13.998       | 15.6769      | 15.674       | 15.6736      |
| 100             | 15.9955      | 16.5529       | 16.6066      | 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      |
| 320             | 25.8649      | 26.8773       | 27.0419      | 56.1462      | 56.1513      | 56.1371      |
| 340             | 26.0624      | 27.0855       | 27.2516      | 60.3813      | 60.3872      | 60.3715      |
| 360             | 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              | 15.4944      | 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       |
| 320             | 3058.56                  | 3435.94                  | 3457.45      | 273.5        | 537.77       | 537.17       |
| 340             | 3081.95                  | 3462.67                  | 3484.38      | 294.24       | 578.92       | 578.21       |
| 360             | 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        | 33.91        | 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        |
| 320             | 864.78                   | 995.95                   | 996.74       | 74.87        | 141.45       | 141.29       |
| 340             | 920.08                   | 1059.9                   | 1060.72      | 82.84        | 156.62       | 156.42       |
| 360             | 944.43                   | 1088.06                  | 1088.89      | 86.73        | 164.01       | 163.8        |

DOI: 10.1051/matecconf/201710302022
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 modes. 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 around15 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.

References

[1] ADIBC 2013, Abu Dhabi international building code, 1, The Higher Building Code Committee Abu Dhabi, United Arab Emirates, (2013)
[2] ACI Committee 224, Joints in concrete construction, 3, ACI, US, (2001)
[3] ACI Committee 209, Prediction of creep, shrinkage, and temperature effects in concrete structures, 1, ACI, US, (1997)
[4] SCSE Committee, Expansion joints in buildings, 65, National Academy of Sciences, Washington, D.C., US, (2000)
[5] ACI Committee 330, Guide for design and construction of concrete parking lots, 1, ACI, US, (1997)
[6] The International Federation for Structural Concrete (Federation international du beton, fib), fib Model Code for Concrete Structures 2010, 1, Wiley, Germany, (2010)