THE Thermal Response of Concrete Frame Buildings in Arabic Area Considering Time-Dependent Properties of Concrete

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Abstract: The Arabic area is known for its high temperatures especially during the summer period. It affects the structural displacements and stresses in concrete elements. The main objectives of this paper are to study the effects of thermal loads on the response of super-long reinforced concrete frame buildings in the Arabic area and regions with similar temperature variation, accounting for various design aspects considering both methodologies of time-dependent properties of concrete as per CEB FIP 90 code and non-time dependent properties as per ACI 224.3R. To achieve these objectives a total of 272 one-storey reinforced concrete frame buildings are numerically modeled and analyzed using the finite element procedures of ETABS. The models are divided into two different groups. The first group is with columns fixed supports, the second group is with columns hinged supports. Each group is analyzed twice: once with time-dependent concrete properties, and another with non-time dependent concrete properties. The study findings are utilized to develop a clear understanding of mentioned variable's effects at thermal deformations and column reactions to aid structural engineers in the thermal design of super-long buildings with similar conditions of this study within time. The horizontal deformations values increase proportionally with the increase of slab length and column height. The horizontal reactions increase proportionally with the increase of slab length and slab thickness values. Fixed columns horizontal reactions are more than horizontal reactions related to hinged column conditions while column height is inversely proportional with the lateral reaction's values. The ratios of time-dependent deformation and reaction to those of non-time-dependent properties are within the range [159%-163%] and [168%-171%] respectively. Ignoring this difference imposes defects, additional cracks, and damages at the structures and related serviceability conditions for 70 years period.

Keywords: Deformation, Non-Time Dependent Properties, Reaction, Time-Dependent Properties

I. INTRODUCTION

In this paper, an investigation of thermal loads fluctuation impact at concrete frame buildings will be conducted to recognize concrete shrinkage and daily fluctuation temperature loads effect at concrete slab considering both methodologies of time-dependent properties of concrete as per CEB FIP 90 code and non-time dependent properties as per ACI 224.3R. It is important to gain a deep understanding of the imposed deformations and forces at the structural elements within time to avoid the risk of overstressed elements which lead to defects in buildings' serviceability [1]. The horizontal deformations and forces for the studied one storey frame buildings with accounting for time-dependent properties of concrete including creep and shrinkage will be presented. A comparison between the results obtained with accounting for time-dependent properties of concrete and that from the concrete frame buildings with non-time dependent properties will be carried out to enable comparing both methods results.

II. METHODOLOGY

A. Used methods

Two groups of three-dimensional finite elements Etabs models are generated. Both group models have the same geometrical properties with similar element sizes. The first group of ETABS models will be analyzed with time-dependent concrete properties for 70 years period considering the CEB-FIP 90 code method which is considered in the ETABS program while the second group of models will be analyzed with non-time dependent concrete properties with concrete strength of 40(N/mm²) hence this value is almost used for concrete buildings in Arabic area considering ACI 224.3R method. For each group two different support conditions will be considered, the fixed and the hinged columns support. Other variables will be considered in ETABS models such as two values for column height: 3 (m) and 6 (m). Slab length will be increased from 60(m) to 400(m) with 20(m) increments and two different slab thicknesses: 0.3 (m) and 0.4 (m) as a safe flat slab for punching and deflection. The thermal expansion coefficient of the concrete value of (0.0000099/C⁰) can be used for unknown conditions of aggregate type and saturation degree of concrete [2] and [3]. The concrete building under conditions of cooling and shrinkage has a high probability of cracking [4]. Consequently, the building constructed in summer will be subjected to a high possibility of tension cracking than others constructed in the winter season [5], so we can apply temperature reduction in all Etabs models.

B. Defining thermal loads values for non-time dependent properties models

Two different methods are presented in ACI 224.3R. The first method is related to Martin and Acosta whereas. ΔT is the summation of the daily temperature changes and shrinkage,
whereas Ts is -17°C = -30°F for drying shrinkage consideration. The design temperature with maximum daily variation is 9-43 = -34°C as shown in Fig. (1). while Ts is 17°C, the total variation will be

$$\Delta T = \frac{2}{3} (T_{\text{max}} - T_{\text{min}}) + Ts$$

(1)

The second method is related to the National Academy of Sciences $\Delta T$ is the largest from:

$$\Delta T = T_w - T_m \text{ or } \Delta T = T_m - T_c$$

(2)

Where $T_m$ is the temperature normally noticed within the construction period. $T_w$ is the high temperature which is just exceeded for a ratio of one percent within the summer’s or the low temperature exceeded ninety-nine percent within the winter season [1]. Historical weather for 1991 shows the maximum difference between January and June [5]. We will presume the construction took place at the highest temperature which took place in June at 47°C, the lowest temperature is in January with a Temperature of 6°C. In this case, the difference is 47-6=41°C, 99%(41) =40°C

We need to consider the higher temperature value between these two methods in Etabs file which is about -40°C.

C. Defining thermal loads and concrete properties for time-dependent properties models

In non–time-dependent properties Etabs models, the maximum temperature variation was applied (-40°C), considering shrinkage as (-17°C), the net temperature fluctuation is 40-17=23°C, this temperature fluctuation -23°C is considered in time-dependent properties Etabs files in addition to creep and shrinkage loads to compare time-dependent properties with non-time dependent properties results. Etabs can define concrete creep, shrinkage, and daily fluctuation temperature loads effect at concrete slab considering time-dependent properties of concrete as clarified in Fig. 3 below

Fig. 3: Time-dependent concrete strength used in Etabs

The considered time is 70 years, the same period is recommended in CEB FIP, 1990. The time-dependent type is CEB-FIP Model code-90. The relative humidity is 60% as the mean average value in the Arabic area, the national size is 300 mm and 400 mm same values of the slab thickness (ACI Committee 209R, 1997).

III. RESULT AND DISCUSSION

A. Analysis of displacements considering non-time dependent properties of concrete

Fig. 4 shows the 3D view of a typical ETABS model.

Fig. 4 The three-dimensional view from Etabs
While Fig. 5 shows the slab plan from ETABS model.

Fig. 5 the slab plan from Etabs model.
An analytical study was conducted to investigate the impact of temperature load fluctuations on three-dimensional one story frame system buildings in Arabic areas with different design aspects. These study results are shown in Figure (5). It is obvious that maximum horizontal deformations UY values which are parallel to slab length are recognized at slab edges-axis (a) and (k). The thermal deformations increase proportionally with the increase of slab length and column height. The results also indicate that using thicker slabs will reduce the horizontal deformations for hinged column conditions while a slight increment is observed in the lateral deformations for models with 40 cm slab thickness and fixed column conditions compared with those for models with 30 cm slab thickness. In general, all single storey finite element analysis models have horizontal deformations less than

\[ \Delta_{h} \approx \alpha \Delta t \cdot \frac{1}{2L} \]  \hspace{1cm} (3)

which is the half deflection of external joints developed in an unrestrained frame as expressed in ACI Committee 224.3R. The upper graph with high thermal deformations belongs to hinged columns supports with 6m storey height. Hinged columns support models’ deformations are more than horizontal deformations related to models with fixed column supports for both column’s heights. The lower graph of deformations belongs to fixed column models with 3m column height.

Fig. 7 Horizontal deformations at peripheral columns slab thickness 40cm.

Fig. 8 Horizontal deformations at peripheral columns slab thickness 30cm.

B. Analysis of reactions considering non-time dependent properties of concrete

A detailed analysis is conducted to investigate the impact of temperature load fluctuations in the Arabic area on peripheral columns reactions forces, the middle column at external slab edges at axis k and a. The results and correlated equations are presented in Figures (8) and (9). It is clear from both figures that models with thicker slabs have greater horizontal reactions. For instance, the reaction at the upper curve in Figure (8) is close to 4500KN for fixed models with 3m column height and 40cm slab thickness, while it reduced to 3500KN for similar models with 30cm slab thickness. The horizontal reactions increase along with slab length and fixity conditions. Meanwhile, these reactions are inversely proportional to the height of the column, consequently, the slab thickness factor seems with high importance at reaction results while its impact was minor at lateral thermal deformations values.
C. Analysis of reactions considering time-dependent properties of concrete

Figures (10) and (11) display the horizontal reactions at the critical peripheral column with the biggest value of reaction, the middle column at external slab edges at axis k, and a. It shows that the horizontal reactions (FY) of fixed columns are greater than those of hinged columns, thereby suggesting that fixed column models require larger footings, columns and rebars than hinged one's under-considered thermal effects. Column height is inversely proportional to thermal reaction. The upper graph is related to concrete buildings with fixed support conditions and 3 m story height, they have the largest and most critical reactions exceeding 6000KN for super-long slabs. The horizontal reactions related to these ETABS models (7157KN /TH 40cm and 6100KN/TH 30cm) are also three times larger than those related to models with 6 m column height (2316KN/TH 40cm and 1848KN/TH 30cm). Moreover, the reactions of fixed column models with 50 m slab length and 3 m storey height (2233KN /TH 40cm and 1955KN/TH 30cm) are 8 to 15 times larger than those of hinged column models (268 KN/TH 40cm and 127.5KN/TH 30cm).

D. Comparison of results between time-dependent and non-time dependent models:

Firstly, there will be a comparison between time-dependent properties (T.D.P) and non-time dependent properties (N.T.D.P.) models results regarding the imposed deformations at the structural system. Fig.s (12) and (13) present the horizontal deformations for all models with time-dependent properties and non-time dependent properties considering all previous variables. These Figures show that time-dependent horizontal deformations are greater than those of NTDP models for all cases under all conditions with respect to the similarity in column height, slab thickness and support condition.
Table I presents horizontal deformations ratios for time-dependent properties to non-time-dependent properties with minimum and maximum values of 158% and 163%, respectively. These additional deformations imposed by the time-dependent method exceed significantly those of the non-time-dependent method. Ignoring the difference in these deformations can lead to defects in the structural elements and serviceability of buildings throughout their life span of 70 years due to excessive deformations at slab edges which affect brittle materials of the elevations in addition to the imposed cracks in slabs under tension stresses.

Table II Ratios of horizontal deformations for time-dependent properties to non-time dependent properties Models

| Slab thickness (cm) | Height (m) | Fixed | Slab thickness (cm) | Height (m) | Fixed |
|--------------------|------------|-------|--------------------|------------|-------|
| 30                 | 163%       | 163%  | 30                 | 162%       | 162%  |
| 60                 | 162%       | 162%  | 60                 | 162%       | 162%  |
| 90                 | 162%       | 162%  | 90                 | 162%       | 162%  |
| 120                | 162%       | 162%  | 120                | 162%       | 162%  |
| 150                | 162%       | 162%  | 150                | 162%       | 162%  |
| 180                | 162%       | 162%  | 180                | 162%       | 162%  |
| 200                | 162%       | 162%  | 200                | 162%       | 162%  |
| 220                | 162%       | 162%  | 220                | 162%       | 162%  |
| 240                | 162%       | 162%  | 240                | 162%       | 162%  |
| 260                | 162%       | 162%  | 260                | 162%       | 162%  |
| 280                | 162%       | 162%  | 280                | 162%       | 162%  |
| 300                | 162%       | 162%  | 300                | 162%       | 162%  |
| 320                | 162%       | 162%  | 320                | 162%       | 162%  |
| 340                | 162%       | 162%  | 340                | 162%       | 162%  |
| 360                | 162%       | 162%  | 360                | 162%       | 162%  |
| 380                | 162%       | 162%  | 380                | 162%       | 162%  |
| 400                | 162%       | 162%  | 400                | 162%       | 162%  |
| Average            | 162%       | 162%  | Average            | 162%       | 162%  |

Table III displays the ratios of horizontal reaction forces of time-dependent properties to non-time dependent properties. The TDP models generally have higher thermal fluctuation and shrinkage reactions than the NTDP models with the minimum, maximum and mean ratios of 167%, 175% and 170%, respectively. This difference in reactions is major. The structural engineer must consider its effects on all columns, slabs and footings design. Additional thermal reactions require adequate steel bars within the mentioned structural members. The thermal forces at footings require adequate friction forces between the footings and the soil in addition to steel bars.
Table IV: Ratios of horizontal reactions for time-dependent properties to non-time dependent properties models

| Slab length (m) | Sub slabs: W/ h cm | Sub slabs: h cm | Column height (m) | Column height (m) |
|----------------|--------------------|----------------|------------------|------------------|
|                | hinged             | fixed          | hinged           | fixed            |
| 0.5            | 1.71%              | 1.71%          | 1.71%            | 1.71%            |
| 1.0            | 1.71%              | 1.71%          | 1.71%            | 1.71%            |
| 1.5            | 1.71%              | 1.71%          | 1.71%            | 1.71%            |
| 2.0            | 1.71%              | 1.71%          | 1.71%            | 1.71%            |
| 2.5            | 1.71%              | 1.71%          | 1.71%            | 1.71%            |
| 3.0            | 1.71%              | 1.71%          | 1.71%            | 1.71%            |
|                | Average            |                |                  |                  |

IV. CONCLUSION

The effect of support condition, column height and slab thickness on the thermal response of reinforced concrete buildings based on TDP of concrete is essential. Given that an increment in slab thickness reduces the horizontal deformations, axial stiffness is directly proportional to slab thickness and area. In this case, thicker slabs have higher stiffness with lower thermal deformations and higher reactions. The deformations of models with hinged column support conditions are greater than those of models with fixed column support conditions. Increasing column height reduces significantly the forces and stresses due to reducing the column stiffness. However, the thermal response of super-long reinforced concrete buildings considering time-dependent properties of concrete is more than those for non-time dependent properties of concrete for all analyzed cases. This variance increases with time throughout the life span of the building. Such variance also imposes additional strains, forces and stresses. The results of this study highlight the importance of analyzing such phenomena and their effects whilst taking the entire life span of the building.

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