The Effects of Seasonal Thermal Loads at Expansion Joints Locations in Arabic Area buildings

Ikhlass Sydnaoui, Roslli Bin Noor Mohamed, Mariyana Aida Binti Ab.Kadi†

Abstract: Concrete buildings are subjected to fluctuation in seasonal temperature loads between summer and winter in the Arabic area. The long-term effects on buildings of such temperatures, along with the frequent fluctuation in the seasonal temperatures impose overall structural deformation, displacements, and alteration of stresses in concrete elements. The thermally induced deformations affect the serviceability conditions of buildings with time. Concrete creep and shrinkage will increase the cracks widths and the imposed stresses too. To eliminate this phenomenon’s effects, expansion joints should be provided. However, as per the building’s functions and trend to develop unique buildings by designers, joint-less buildings are usually the preferred option. When using this option, the structural engineer has to consider the effects of thermal load changes in the design. A proper methodology must be provided to define the maximum allowed spacing between expansion joints in addition to a clear process for buildings thermal study. Different approaches are provided by researchers, each methodology provides different values for required joints spacing considering different aspects in design. In this paper, I shall try to present three methods with a comparison study for considered aspects and gaps for each method analysis to propose the most appropriate methodology to support engineers in calculating the maximum allowed spacing between expansion joints.

Keywords: fluctuation, long-term; expansion joints; thermally

I. INTRODUCTION

Shrinkage and creep of concrete are influenced by environmental aspects such as the weather relative humidity and seasonal temperature variations [1]. Temperature variations creep and shrinkage directly affects the life span of concrete buildings, the hydration of cement at high values of temperature imposes changes in the cement properties. The deformation of creep increases at 50 °C to be three times more than strains at (20-25 °C). The temperature range of fifty to eighty degrees causes the largest value of creep [1]. The superposition of humidity, creep, shrinkage and temperature variations have a similar type of stresses and strains [2]. The concrete deformation is the superposition of shrinkage strain, creep strain, cracking and thermal strain. The longer-term effects of temperature are imposed due to the largest variation of winter and summer temperature, the most important value is the maximum variation in temperature. The changes in concrete Volume related to temperature variations and ambient environment moisture have to be analyzed within the structural calculations of the reinforced concrete buildings whereas the building movements and the forces related to changes in building volume are related to the size of the building segments without separation joints [3]. The contraction and the expansion of concrete is the summation of the variations in the volume of concrete under seasonal temperature variations. The critical response of super long premises is related to the decrease in ambient environment temperature accompanied by shrinkage of concrete [4]. These premises are subjected to high stresses and deformations under thermal loads. To eliminate this issue, structural engineers provide expansion joints. Expansion joints are used to decrease the deformations of thermal loads and correlated forces between adjacent segments of the building. Expansion joints decrease the width of contraction cracks hence these joints are protected by thermal insulation, so they can be considered as insulation and expansion joints [5]. Expansion joints allow for the contraction and the expansion of buildings under the variation of thermal loads changes within acceptable limits of stresses and deformations [5-6].

II. METHODOLOGY

A. used methods

The designer engineer defines the exact location of thermal separations considering the variation in the building volume related to thermal effects. Some methods were provided by SCSE Committee in 1974 for expansion joints locations and conditions. These methods are used in the Arabic area to define joints spacing. The location of expansion joints is from the roof slab down to footings. It is allowed to provide one footing for separated segments of the building [6]. The
width of the expansion joint has to be adequate to prevent building segments from contact under maximum predicted temperature loads [5]. Elongation (T) in a building subjected to temperature can be defined from this equation:

\[ T = a \cdot L \cdot (t_{\text{max}} - t_{\text{min}}) \]

where (a) is the expansion thermal coefficient of concrete, (L) is the building length, and \((t_{\text{max}} - t_{\text{min}})\) is the difference in temperature loads between summer and winter [3].

In the Arabic area, the spacing between expansion joints under thermal loads could be calculated considering different methods such as Martin and Acosta which is applicable under specific conditions, the National academy of sciences, and the analytical method.

**B. Martin and Acosta (ACI Committee 224.3R, 2001):**

It is considered for one story concrete frame buildings with almost similar spans. There is an equation that calculates the expansion joint spacing (L_j) between adjacent parts of the building segments from Figure (1) in feet:

\[ L_j = \frac{112000 \cdot (R \cdot \Delta T)}{144} \]  

where \( R \) is related to the stiffness of used columns and beams:

\[ R = \frac{144 \cdot lc(1+r)}{h^2(1+2r)} \]  

\( r \) is related to columns and beams stiffness \( r = K_c/K_b \) while \( \Delta T \) is the summation of daily temperature changes and shrinkage:

\[ \Delta T = \frac{2}{3} (T_{\text{max}} - T_{\text{min}}) + T_s \]  

whereas Ts is \(-17^\circ\text{C} = -30^\circ\text{F}\) for drying shrinkage consideration.

![Fig. 1. Expansion joints separation for one-story concrete frame building versus variation in daily temperature [3].](image1)

This method ignored many factors which affect stresses in concrete buildings such as: the used concrete properties, the columns support conditions, the used span between columns, the shape of the building, the slabs thicknesses and the life span of the building, which are important factors with direct impact at the building long term stresses. The question here: is it logic to use same joints spacing for concrete frame buildings regardless these mentioned points?

**C. National Academy of Sciences Method**

Federal agencies used Figure (2) below to define the expansion joints spacing with respect to temperature changes. It is rules of thumb and expert engineers’ consensus without analyzing or calculations. Figure (2) shows that the increment in variation between maximum or minimum annual temperature and the mean temperature at pouring period will decrease the expansion joints spacing and the length of related building segments. The maximum allowed building length is on contrary with annual temperature diversity. The upper and lower limits are 200ft and 600ft for expansion joint spaces as shown in Figure (2). It is engineers consent for all different materials without engineering substantiations [7-8].

![Fig. 2. The allowable spacing between building segments in feet [3-8].](image2)

The national academy of sciences considered the curve in figure 2 for the allowable building segments between expansion joints. A comparison study was initiated by Public Buildings Administrations between the theoretical effect of temperature changes on two frames buildings and the actual strains observed in one year. This comparison led to developing figure (3) below by the SCSE 2000 committee.

![Fig. 3. Expansion joint spaces as SCSE committee 2000. [3-6].](image3)
The SCSE Committee (2000) captured some conclusions considering the results of a previous study was prepared by Public Building Administration on existing buildings which considered the strains of the expansion joints in these mentioned buildings. They found out that: hinged columns force reactions at its base are lower than fixed columns values. The imposed thermal stresses are proportional to the structural element’s sizes. The width of the expansion joint will increase for hinged columns premises [3-9]. The thermal deformations at upper levels above the 1st slab for hinged and fixed columns supports are symmetrical. Some conditions are provided such as: reducing the allowable limit of the joint spacing by 15 % for buildings with fixed conditions at column supports. The updated function in Figure (3) considers heated buildings with columns supports conditions at their base. Modification factors are required for buildings subjected to air conditions heating or cooling. Increasing the allowable joints spacing by 15 % for heated buildings. Reducing the allowable segments’ length by 33% for non-heated premises. It is noted that this method ignored many factors such as the impact of the used concrete properties, the columns height, shrinkage and creep effects, the used span between columns, the shape of used buildings and stories number in addition to the design life span of the building.

D. The analytical method (SCSE Committee, 2000).

The complexity of building shape, displacements and stresses imposed by temperature fluctuation makes it impractical to define the spacing between joints by using the aforementioned methods. In these cases, an accurate structural analysis must be followed whilst considering changes in temperature and after reaching a compromise between the serviceability and capacity of buildings against the imposed forces and their capability to withstand thermal displacements. Computer analysis is essential to conduct the required analysis for stresses and deformations and to help engineers to define the capacities of the buildings [6]. For large and indeterminate structures, simple mathematical expressions cannot be used. It is essential to consider the construction details, the properties of materials, the building geometry by computer analysis for proper understanding of imposed forces distributions and deformations evaluation.

III. RESULT AND DISCUSSION

Defining the maximum allowed spacing between building joints and segments is essential for architectural and structural engineers. The structural engineer has to define the joint’s proper locations in the early design stage. So, there is a need to have procedures to provide clear assumptions and accurate acceptable methods to allocate the expansion joints in early design stages considering building integrity and serviceability to avoid its impact on the architectural design in late design stages or any additional costs variations within the construction stage. The maximum allowed slab length providing expansion joints calculations is calculated considering the Martin and Acosta method, National Academy of Sciences [3] and analytical finite elements method. Both empirical methods are specified in American standards and used in the Arabic area. They are accepted by the authorities. The same methods will be used in this paper to conduct a comparison study in results and allowed joints spacing. Following are the variables that will be considered in this study for concrete frame buildings with two values for column height: 3 m and 6 m, slab thickness are 30cm and 40cm. Columns sizes: 80x80 cm2 with beam span 10m, two columns supports conditions are considered fixed and hinged. The design temperature maximum daily variation is: whereas Ts is -17(Cº)=-30(Pº) for drying shrinkage consideration. The design temperature with maximum daily variation is 9-43=-34(Cº) as shown in Fig. (1), while Ts is 17(C), the total variation will be

\[ \Delta T = \frac{2}{3}(T_{max} - T_{min}) + Ts= 22.6 + 17 = 39.7°C. \]

![Fig. 4. The daily lowest and highest temperature during 1997 (A.D.I.A, 2015)[11]](image)

A. Martin and Acosta- method (A)

Tables (I) and (II) clarify the concrete frame buildings stiffness properties and the maximum allowed spacing between expansion joints Lj for concrete frame buildings as per Martin and Acosta method for slab thickness 30cm for columns heights 3m and 6m. All element sizes are presented in cm and inch. The maximum allowed spacing between expansion joints is 63m and 126.2m for both columns’ heights 3m and 6m respectively regardless of the slab thickness value.

<table>
<thead>
<tr>
<th>Column height (m)</th>
<th>Column size (cm²)</th>
<th>Stiffness factor of column IC (kN/m²)</th>
<th>Stiffness factor of beam IC (kN/m²)</th>
<th>Stiffness factor of column (IC=0 or IC=) (kN/m²)</th>
<th>Stiffness factor of beam (IC=0 or IC=) (kN/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3m</td>
<td>80x80</td>
<td>0.0018</td>
<td>0.0018</td>
<td>0.0142</td>
<td>0.0057</td>
</tr>
<tr>
<td>6m</td>
<td>80x80</td>
<td>0.0018</td>
<td>0.0018</td>
<td>0.0142</td>
<td>0.0057</td>
</tr>
</tbody>
</table>

Table-I: The columns and beams stiffness values for concrete building with 30cm slab thickness

<table>
<thead>
<tr>
<th>Column height (m)</th>
<th>Stiffness factor for beams (IC=0 or IC=) (kN/m²)</th>
<th>I (cm⁴)</th>
<th>R (cm³)</th>
<th>Lj (cm)</th>
<th>Lj max. (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3m</td>
<td>0.00018</td>
<td>65.4</td>
<td>0.281</td>
<td>118.7</td>
<td>63</td>
</tr>
<tr>
<td>6m</td>
<td>0.00018</td>
<td>31.7</td>
<td>0.07</td>
<td>457</td>
<td>126</td>
</tr>
</tbody>
</table>

Table- II: The allowed expansion joint spacing in the meter for concrete frame building with slab thickness 30cm and columns height 3m and 6m.

Tables (III) and (IV) clarify the concrete frame buildings stiffness properties and the maximum allowed spacing between expansion joints Lj for concrete frame buildings as per Martin and Acosta method for slab thickness 40cm for columns heights 3m and 6m. All element sizes are presented in cm.
Table III: The columns and beams stiffness values for concrete frame building with slab thickness 40cm.

<table>
<thead>
<tr>
<th>Column height (m)</th>
<th>Column size (cm²)</th>
<th>Interia of column IC (cm⁴)</th>
<th>Beam size (widthdepth) (cm)</th>
<th>Interia of beam IB (cm⁴)</th>
<th>Stiffness factor for columns (G/E=950) (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3m</td>
<td>80x80</td>
<td>0.334</td>
<td>80x40</td>
<td>0.00427</td>
<td>0.01142</td>
</tr>
<tr>
<td>6m</td>
<td>80x80</td>
<td>0.334</td>
<td>80x40</td>
<td>0.00427</td>
<td>0.0057</td>
</tr>
</tbody>
</table>

Table -IV: The allowed expansion joint spacing in the metre for concrete frame building with slab thickness 40cm and columns height 3m and 6m.

<table>
<thead>
<tr>
<th>Column height (m)</th>
<th>Stiffness factor for beam (G/E=950) (cm)</th>
<th>r (kN/m)</th>
<th>R (kN/m)</th>
<th>Lj (mm)</th>
<th>Lj max (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3m</td>
<td>0.0099427</td>
<td>26.7</td>
<td>23.882</td>
<td>117.5</td>
<td>13.1</td>
</tr>
<tr>
<td>6m</td>
<td>0.0099427</td>
<td>13.33</td>
<td>0.07986</td>
<td>467</td>
<td>128.1872</td>
</tr>
</tbody>
</table>

B. National academy of sciences- method (B):

ΔT is the largest from ΔT=Tw-Tm, or ΔT=Tm-Tc. Where, Tm is the temperature normally noticed within the construction period. Tw is the high temperature which is just exceeded for a ratio of one percent within the summer. Tc is the low temperature exceeded ninety -nine percent within the winter season (ACI Committee 224.3R, 2001) and Tm is the temperature of weather at construction. Historical weather for 1991 (Figure 5) shows the maximum difference between January and June. 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.

Fig. 5 The daily lowest and highest temperature during 1991 [11].

Using Fig 3, the allowable spacing is 121.9m for hinged columns between expansion joints. For fixed columns, we need to apply a decrement of 15% and the allowed spacing will be 121.9*0.85=103.6 m.

As a conclusion of these methods results, table (V) below clarifies the maximum allowed spacing between expansion joints of adjacent building segments considering the empirical approaches Martin and Acosta and the National Academy of sciences. There is a clear variation in allowed spacing values. For columns with a height of 3m, the National academy of sciences allowed spacing between expansion joints 121.9m and 103.6m are much larger than Martin and Acosta method value 82.3m for hinged and fixed columns support consequently, while Martin and Acosta method values increased to 126.18m for columns with height 6m with constant values for National academy of sciences method which ignored the effect of story height. It is observed that Martin and Acosta’s method ignored the fixity condition and slab thickness but considered columns height, columns inertia, beams inertia, temperature variation, and shrinkage impact. Whereas, the National academy of sciences method considered the fixed supports condition, the hinged condition, temperature variation and ignored columns height. It ignored all structural elements stiffness and don’t have a clear limitation for the maximum allowable lateral deflection.

Table-V: maximum allowed spacing between joints from empirical approaches in (m)

<table>
<thead>
<tr>
<th>Empirical methods</th>
<th>Fixed column conditions</th>
<th>Hinged column conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>column height 3m</td>
<td>column height 6m</td>
</tr>
<tr>
<td></td>
<td>column height 3m</td>
<td>column height 6m</td>
</tr>
<tr>
<td>Martin and Acosta</td>
<td>63</td>
<td>126</td>
</tr>
<tr>
<td>National Academy of Sciences</td>
<td>121.9</td>
<td>121.9</td>
</tr>
</tbody>
</table>

144 finite element Etabs-three diminutions models are generated. The concrete strength is 40N/mm² hence this value is almost used for concrete buildings in The Arabic area. two different support conditions are considered, the fixed and the hinged columns support. The variables considered in ETABS models are Column height: 3 m and 6 m, slab length range [50m to 400m] with 20m increment, slab thickness 0.3 m and 0.4 m as a safe flat slab for punching and deflection. Slab width is fixed: 50 m. The thermal expansion coefficient of concrete value 10x10-6°C can be used for unknown conditions of aggregate type and saturation degree of concrete [10,12] Modulus of elasticity (E) = 30000 MPa, Ec=4750√fc [13], Poisson ratio for concrete was considered=0.2. The temperature value is the highest between the previous two methods (method A and method B) in the Etabs file. So it will be considered -40°C. Figure 6 shows the slab and columns of a typical model. Figure 7 presents deformations under thermal loads for the slab. Maximum deformations parallel to slab length are recognized at slabs edges, so columns at slab edges are subjected to the largest displacements and the are the critical columns under thermal loads, so they will be considered in the study.
The maximum deformations for hinged columns seem identical at the slab edge as shown in figure 5. All columns deformations have almost the same values. While, the maximum horizontal deformations for fixed columns conditions are recognized at column O (the third peripheral column). Due to this result, column deformations will be analyzed considering the critical column O. Figure 8 clarify that columns M, N and O horizontal deformations for smaller slabs lengths models are closer to \( \Delta = \alpha \Delta t (1/2L) \) values related to thermal deformation of unrestrained slab [3,12] than longer slabs lengths. It supports the structural engineer’s calculations and analysis for deformations values.

Fig. 8 presents that horizontal deformations (UY) parallel to slabs length 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 and super-long slabs for fixed conditions. In general, all single storey finite element analysis models have horizontal deformations smaller than \( \Delta = \alpha \Delta t (1/2L) \) values, which is the half deflection of external joints developed in an unrestrained frame [3].

The allowed lateral deformation as per Martin and Acosta method is \( h/180 \). For columns height 3m and 6 m the allowed deformations are 16.67 mm and 33.33mm respectively. The maximum allowed spacing between joints is defined considering these limits as shown in figures 9 and 10.
An expansion joint needs to be installed for slabs under the fixed column support condition and with lengths exceeding 101 m for both slab thicknesses and 3 m column height models, this distance increase significantly to 184 m for similar models with a column height 6m. Meanwhile, the limit for slabs under the hinged column support conditions and 3 m column height is 89 m because the deformations under this condition are greater than those under the fixed column support condition as shown in Table VI. Therefore, intersection points of deformation curves and limit lines of 3m models have less slab length. Those buildings with 6 m column height have a deformation limit of up to 33.3 mm. According to Figures 7 and 8, the allowable spacing between joints with 30 cm slab thickness and fixed column support is 187.72 m. However, when the slab thickness increases to 40 cm, this spacing decrease to 184.2 m. Meanwhile, the maximum allowable spacing for models with 6 m column height and hinged column support is reduced to 176.5 m because this column support condition has a higher thermal deformation than the fixed one. Therefore, the intersection points of deformation curves with the limit line of 6m models will have lesser slab lengths between expansion joints. Table VI presents the maximum allowable spacing between expansion joints for all cases and shows that the difference in slab thickness has a minor impact on the allowable spacing. Therefore, the allowable spacings for hinged models with 30 cm and 40 cm slab thicknesses and 3m column heights are almost similar as 89.023 m and 89.02 m, respectively. While this difference increased to 8 m for hinged models with 6m column height. Similarly, the allowable spacings for fixed models with 30 cm and 40 cm slab thicknesses and 3m column heights are 107.8 m and 101.14 m, respectively. In sum, the difference in the allowable spacing for both slab thicknesses is less than 8 m, while both column height and support condition have major impacts on maximum spacings between expansion joints ranging from 89.02 m to 187.7m.

Table VI: The maximum allowed spacing between Joints

<table>
<thead>
<tr>
<th>Slab thickness (cm)</th>
<th>Column height (m)</th>
<th>Hinged columns</th>
<th>Fixed columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>5</td>
<td>89.02 m</td>
<td>107.8 m</td>
</tr>
<tr>
<td>40</td>
<td>5</td>
<td>89.023 m</td>
<td>101.14 m</td>
</tr>
<tr>
<td>30</td>
<td>6</td>
<td>107.8 m</td>
<td>187.72 m</td>
</tr>
<tr>
<td>40</td>
<td>6</td>
<td>101.14 m</td>
<td>184.2 m</td>
</tr>
</tbody>
</table>

IV. CONCLUSION

The spacings between expansion joints for the analysed models are defined by using all methods, including the approaches of Martin and Acosta and the National Academy of Sciences and NTDP models. In sum, Martin and Acosta method returned a constant allowable spacing for all models with respect to column height. Meanwhile, the approach of the National Academy of Sciences obtains an allowable spacing of 122 m for hinged models, which is 15% higher than that for fixed models. For buildings with 3 m column heights, the allowable spacings computed by using the approach of Martin and Acosta are less than those obtained by other methods. Meanwhile, the allowable spacings computed by NTDP for fixed model conditions with 30 cm and 40 cm slab thicknesses are close to the results of the National Academy of Science. Regarding models with 6 m column height, the NTDP joint spacings exceed those of the empirical methods. Also, a clear variance in the allowable spacings is observed for all models as per the empirical methods.

As shown in the table VII, each method obtains unique values for the maximum allowable spacing between expansion joints. Specifically, the approach of Martin and Acosta returned a constant allowable spacing of 3 m (63 m spacing) and 6 m (126 m spacing) for all models. These spacings are proportional to column height. Meanwhile, the approach of the National Academy of Sciences always returns the highest spacings for models with 3m column heights. Meanwhile, the allowable spacings computed by NTDP for fixed model conditions with 30 cm and 40 cm slab thicknesses are 107.8 m and 101.14 m, respectively which are close to the results of the National Academy of Science. The NTDP results for models with 6 m column height exceed the results of the empirical methods. These empirical methods also show a clear variance in their allowable spacings for models with 6m column height.

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Bachelor’s Degree in structural/ civil Engineering, (structure Section), Damascus University, (1999)
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