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 effects, expansion joints should be provided. However, as per the buildings 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 loads changes in the design. Clear rules and standards must be provided to define the maximum joints spacing’s allowed length in addition to thermal study procedures. Different approaches are provided by researchers, each methodology provide different value for required joints spacing considering different aspects in design. In this paper I shall try to present three methods with comparison study for considered aspects and gaps for each method analysis to propose the most appropriate methodology as a tool helps 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 with environment aspects such as the weather relative humidity and seasonal temperature variations [1]. Temperature variations, creep and shrinkage directly affect the life span off 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 fifty to eighty degree causes the largest value of creep [1]. The superposition of humidity, creep, shrinkage and temperature variations have similar type of stresses and strains [2]. The concrete deformation is superposition of cracking strain, creep strain, thermal and shrinkage 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 reduce the thermal loads stresses between building segments. Expansion joints reduce cracks due to contraction by insulating the building segments, so they can act as dual joints of insulation and expansion [5]. Expansion joints allow buildings segments expansion and contraction under thermal loads changes without impact on structure serviceability and integrity [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 Arabic area to define joints spacing. The location of expansion joints is from 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 building subjected to temperature can be defined from this equation $T = \alpha * L *(t_{max} - t_{min})$ whereas (a) is the expansion thermal coefficient of concrete, (L) is the building length and $(t_{max} - t_{min})$ is the difference in temperature loads between summer and winter [3].

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In 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 calculates the expansion joint spacing ($L_j$) between adjacent parts of the building segments from Figure (1) in feet

$$L_j = \frac{112000}{R \cdot \Delta T}$$  \hspace{1cm} (1)

whereas $R$ is related to the stiffness of used columns and beams

$$R = \frac{144 \cdot k}{h^2 (1 + 2r)}$$  \hspace{1cm} (2)

$r$ is related to columns and beams stiffness $r = \frac{K_c}{K_b}$ while $\Delta T$ is the summation of daily temperature changes and shrinkage,

$$\Delta T = \frac{2}{3} (T_{max} - T_{min}) + T_s$$  \hspace{1cm} (3)

whereas $T_s$ is $-17^\circ C = -30^\circ F$ for drying shrinkage consideration.

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].](image)

National academy of sciences considered the curve in figure 2 for the allowable building’s 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 [6].

![Fig. 3. Expansion joint spaces as SCSE committee 2000. [3-6](image)

The SCSE Committee (2000) captured some conclusions considering results of 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 in 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 1st slab for hinged and fixed columns supports are symmetrical. Some conditions are provided such as: reducing the allowable limit of joint spacing by 15 % for buildings with fixed conditions at columns supports. The updated function in Figure (3) considers heated buildings with columns supports conditions at its 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 design life span of the building.

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

The complexity of buildings configuration, deformations and stresses related to temperature changes impact at these buildings make it difficult and impractical to define the joints spacing considering previous methods. In these cases, a proper structural analysis must be conducted considering the temperature change with compromise between building capacity against applied stresses and serviceability with ability to withstand the thermal deformations. A computer analysis is essential to supplement the engineer understanding of the applied stresses, deformations and to define the maximum resisting capacities [6]. For large and indeterminate structures, the simple mathematical expressions cannot be used. It is essential to consider the construction details, the properties of materials, the building geometry by a 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 joints 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 are calculated considering 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. Same methods will be used in this paper to conduct a comparison study in results and allowed joints spacing. Following are the variables 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:

37-12=25°C as shown in figure (4). while Ts is 17°C , The total variation will be

\[ \Delta T = \frac{T_{\text{max}} - T_{\text{min}}}{2} + Ts \]

16.67+17=34°C.

Fig. 4. The daily lowest and highest temperature during 2013(A.D.I.A, 2015)[11]

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 \( L_j \) for concrete frame buildings as per Martin and Acosta method for slab thickness 30cm for columns heights 3m and 6m. All elements sizes are presented in cm and inch. The maximum allowed spacing between expansion joints are 63cm and 126.2cm for both columns’ heights 3m and 6m respectively regardless the slab thickness value.

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

<table>
<thead>
<tr>
<th>column size ( \text{cm}^2 )</th>
<th>( \text{in}^2 )</th>
<th>IC ( \text{in}^4 )</th>
<th>Beam size ( \text{cm}^2 )</th>
<th>Beam size ( \text{in}^2 )</th>
<th>( b_i ) ( \text{in} )</th>
<th>( Kc/\text{ch} \text{in}^3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>80x80</td>
<td>31.52x11.82</td>
<td>82264.5</td>
<td>80x30</td>
<td>31.5x11.82</td>
<td>4338.2</td>
<td>63.4</td>
</tr>
<tr>
<td>80x80</td>
<td>31.52x11.82</td>
<td>82264.5</td>
<td>80x30</td>
<td>31.5x11.82</td>
<td>4338.2</td>
<td>31.7</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>column size ( \text{cm}^2 )</th>
<th>( \text{in}^2 )</th>
<th>( L_j ) ( \text{feet} )</th>
<th>( L_j \text{max} ) ( \text{feet} )</th>
<th>( L_j ) ( \text{max} ) ( \text{at} \text{slab} ) ( \text{foot} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>80x80</td>
<td>31.52x11.82</td>
<td>82264.5</td>
<td>80x30</td>
<td>31.5x11.82</td>
</tr>
<tr>
<td>80x80</td>
<td>31.52x11.82</td>
<td>82264.5</td>
<td>80x30</td>
<td>31.5x11.82</td>
</tr>
</tbody>
</table>

Tables (III) and (IV) clarify the concrete frame buildings stiffness properties and the maximum allowed spacing between expansion joints \( L_j \) for concrete frame buildings as per Martin and Acosta method for slab thickness 40cm for columns heights 3m and 6m. All elements sizes are presented in cm and inch. 

<table>
<thead>
<tr>
<th>column size ( \text{cm}^2 )</th>
<th>( \text{in}^2 )</th>
<th>( L_j ) ( \text{feet} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>80x80</td>
<td>31.52x11.82</td>
<td>82264.5</td>
</tr>
<tr>
<td>80x80</td>
<td>31.52x11.82</td>
<td>82264.5</td>
</tr>
</tbody>
</table>
### 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>Slab Thickness 40cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Column Size (cm²)</td>
</tr>
<tr>
<td>3m</td>
<td>80x80</td>
</tr>
<tr>
<td>6m</td>
<td>80x80</td>
</tr>
</tbody>
</table>

### Table IV: The allowed expansion joint spacing in feet for concrete frame building with slab thickness 40cm and column height 3m and 6m.

<table>
<thead>
<tr>
<th>Column Height (m)</th>
<th>Slab Thickness 40cm</th>
<th>kb=ib/l in³</th>
<th>r=kc/kb in³</th>
<th>R</th>
<th>Ljmax=2000h/Δt (ft)</th>
<th>Lj (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3m</td>
<td>80x80</td>
<td>26.1</td>
<td>26.7</td>
<td>440.6</td>
<td>385.52</td>
<td>207</td>
</tr>
<tr>
<td>6m</td>
<td>80x80</td>
<td>26.1</td>
<td>13.33</td>
<td>110</td>
<td>1533</td>
<td>414</td>
</tr>
</tbody>
</table>

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

ΔT is the largest from ΔT=Tm-Tw, 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 2013 (Figure 4) shows the maximum difference between January and August. We will presume the construction took place in January with Temperature 9°C. The highest temperature took place in August 48°C. In this case the difference is 48-9=39°C. Using Fig 3, the allowable spacing is 400ft for hinged columns between expansion joints. For fixed columns, we need to apply decrement 15% and the allowed spacing will be 400-400*0.15=340ft.

As 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 National Academy of sciences. There is a clear variation in allowed spacing values. For columns with height 3m, National academy of sciences allowed spacing between expansion joints 400ft and 340 ft are much larger than Martin and Acosta method value 207ft for hinged and fixed columns supports consequently, while Martin and Acosta method values decreased to 414 ft 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 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 clear limitation for the maximum allowable lateral deflection.

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

<table>
<thead>
<tr>
<th>Column Height (m)</th>
<th>Slab Thickness 40cm</th>
<th>kb=ib/l in³</th>
<th>r=kc/kb in³</th>
<th>R</th>
<th>Ljmax=2000h/Δt (m)</th>
<th>Lj (ft)</th>
</tr>
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<td>3m</td>
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<td>13.33</td>
<td>110</td>
<td>1533</td>
<td>414</td>
</tr>
</tbody>
</table>

**C. Analytical method by finite elements models**

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 condition are considered, the fixed and the hinged columns supports. 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 previous two methods (method A and method B) in Etabs file.so it will be considered -40°C. Figures 5 and 6 show the 3D view and the top view 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 they 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 figures 8 and 9. 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. Figures 8 and 9 clarify that columns M, N and O horizontal deformations for smaller slabs lengths models are closer to $\Delta \approx \Delta t (1/2L)$ values related to unrestrained slab thermal deformations [3,12] than longer slabs lengths. It facilitates the structural engineer’s prediction for displacements values.

Figures 10 and 11 present 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 columns conditions while its impact was not recognized clearly for fixed columns conditions. In general, all single storey finite element analysis models have horizontal deformations smaller than $\Delta = \Delta t (1/2L)$ 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 10 and 11. The spacing between joints is slightly decreased with an increasing in slab thickness. Table VI summarizes maximum allowed spacing between expansion joints for all cases.

Table VI: The maximum allowed spacing between Joints

<table>
<thead>
<tr>
<th>Slab thickness</th>
<th>Column height</th>
<th>Hinged columns</th>
<th>Fixed columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>3m</td>
<td>86.6m</td>
<td>102.6m</td>
</tr>
<tr>
<td>30</td>
<td>6m</td>
<td>170.5m</td>
<td>186.6m</td>
</tr>
<tr>
<td>40</td>
<td>3m</td>
<td>85.67m</td>
<td>99.25m</td>
</tr>
<tr>
<td>40</td>
<td>6m</td>
<td>170.5m</td>
<td>183m</td>
</tr>
</tbody>
</table>
IV. CONCLUSION

The investigation of thermal loads fluctuation is essential to perform a deep understanding about the imposed deformations and stresses within the structural elements. These deformations and stresses must be within the allowed limits to avoid structural failure or serviceability defects. The two empirical methods analyzed in this paper and the analytical finite elements models process provided different values for joints spacing in similar buildings conditions. Table VII presents the maximum allowed spacing between expansion joints from all methods.

Table VII: The maximum allowed spacing between Joints

The national academy of science method spacing is twice the allowed spacing from other methods for building with 3m columns height, while the results of this method seem much closer to analytical methods for frames with 6m columns ‘height. Martin and Acosta method allowed spacing seem more than analytical methods for both frames’ heights with mean ratio 30%. The difference in recommended distances is obvious and cannot be neglected, it confuses the engineers about most appropriate values. These differences are related to ignoring many of important design aspects. Martin and Acosta methods ignored some 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. The second method is related to the National academy of sciences, it is noted that this method neglected the effects 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 design life span of the building. It is important to develop other methods considering these factors.

Finite element analysis study can help in providing a better understanding of the influence of thermal loads and long-term effects of shrinkage and creep on the response of reinforced concrete frame buildings in Arabic area and other areas with similar seasonal conditions whereas modern programs have capabilities of considering the geometry of the building, the columns supports conditions, the variation in temperature, life span of the building and the properties of the used materials.

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