Requirement of expansion joint for temperature load for RCC structures

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Abstract. Concrete is the most commonly used material in building construction. Concrete structures are subjected to seasonal and daily temperature changes due to their interaction with the surrounding environment, in addition to live and dead loads. Significant change of temperature can impose large amount of stress in a structure. These thermal stress values can even exceed the stress values induced by the live and dead loading in case of no or little thermal insulation and could lead to severe damages if not considered during the design. One way of minimizing the temperature stress is to limit lengths of building. In Bangladesh National Building Code and many other national codes, there is no specific guideline for length limits or provision for considering stresses due to temperature load. This paper is aimed to determine the maximum permissible length of a structure without providing an expansion joint so that temperature changes do not create undue stresses. Parametric study involving thermal effect on RCC structures was performed for varying dimensions, conditions and story levels. If temperature effect for structures with significant length is considered, it has been found that top deflection and rebar percentage exceeds limiting values. The finding could become useful in guiding to set the permissible building length without expansion gap.

1. Introduction

Bangladesh experiences moderately high temperature especially in summer season [1]. This high temperature along with the variation in seasonal temperature may lead to thermal differential stresses, deformation, displacements in most structural elements. In cases where deformations due to temperature change are restrained, thermal stresses can be detrimental to RCC structures. Tensile stresses induced in the member can result in cracking and consequent reduction in flexural stiffness. These stresses may also cause failure in serviceability [2]. Because temperature effects do not often affect the ultimate limit state of the structure, effects of temperature on deflection are sometimes not considered in design.

All concrete elements and structures are subject to volume change in varying degrees resulting from thermal and moisture changes, dependent upon the makeup, configuration, and environment of the concrete. Uniform volume change will not produce cracking if the element or structure is relatively free to change volume in all directions [2]. Concrete contraction or expansion is the algebraic sum of these volume changes. Expansion joints limit the magnitude of forces, displacements and cracking induced by temperature [3]. Introducing expansion joints in continuous structures could be a solution for dealing with significant volume change due to high thermal stresses.
In Bangladesh National Building Code (BNBC), the variation of temperature within the material of a structural element is said to be controlled by relieving the stresses by providing adequate numbers of expansion or contraction joints [4]. But there is neither specific provision for interval of expansion joints nor does it specify the temperature as a load to be considered along with other load combinations. Therefore the objective of this paper was to determine the maximum permissible length of a structure without providing an expansion joint to release the stresses in context of Bangladesh climate. In order to do that various finite element models were developed using ETABS for different cases including the application of temperature load. From the models, the maximum allowable length of structure without expansion gap was determined.

In service, thermal effects are related to the difference between the highest temperature during summer and the lowest temperature during winter [2]. The maximum and minimum temperature values were determined from the data of Bangladesh Meteorological Department [1]. Although specific length was identified, more study can be done on effect of temperature change in context of Bangladesh weather.

2. Modelling of the structure
To investigate the effect of thermal loads on RCC structures, twelve different structures were modelled for varying conditions involving bay lengths, number of bays, different story heights, and different load combinations. These variables enabled to create a pattern in the change of deflections and axial forces of the structures.

2.1. Material properties
Properties of structural concrete and reinforcing steel are presented in Table 1.

| Concrete Properties | Values       |
|---------------------|--------------|
| Concrete compressive strength (f_c’) | 4 ksi        |
| Modulus of elasticity (E) | 3600 ksi     |
| Poisson’s ratio      | 0.2          |
| Mass per unit volume | 2.25x10^-7 kip/in^3 |
| Coefficient of thermal expansion | 10x10^-6 /°C |
| Bending reinforcement yield stress (f_y) | 60 ksi       |
| Shear reinforcement yield stress (f_s) | 60 ksi       |

2.2. ETABS model geometry
The constant values of model geometry were taken as follows:

- Slab thickness = 5 inch (125mm)
- Column size = 15 inch x 15 inch (375mm x 375mm)
- Beam size = 20 inch x 10 inch (500mm x 250mm)

Figure 1 shows a typical model of a structure under study. Typical building plan is shown in Figure 2.
2.3. Applied load cases and combinations
Self-weight, live loads, superimposed dead loads, partition wall loads & temperature loads were applied to the models and analysis was done based on load combinations as per BNBC 2006 [4]. Table 2 presents loading values that were applied to the structure models.

Table 2. Values of load assigned.

| Load Cases               | Values | Area of application                      | Comments                                      |
|-------------------------|--------|------------------------------------------|-----------------------------------------------|
| Live load               | 40 psf | Slabs of each floor                      | As per BNBC 2006 for residential buildings   |
| Superimposed dead load  | 30 psf | Slabs of each floor                      | As per BNBC 2006 for residential buildings   |
| Partition wall load     | 0.5 kip/ft | Beams of all storey except the topmost one | 5 inch thick and 10 ft high brick wall       |

2.4. Thermal load calculation
From the data of Bangladesh Meteorological Department, in 2012, the highest maximum temperature of the year was observed in the month of May in the southwest and northwest part of Bangladesh. The maximum temperature was 34.8°C (94.64°F). In other parts of the country, the value of maximum temperature was found to be slightly less. For example, in capital city Dhaka which is situated in the central part of the country, the maximum temperature was observed to be 33.4°C (92.12°F). As the difference in maximum temperature values in various parts of the country is not very significant, same value can be used for all regions. In 2012, the lowest minimum temperature of the year was observed in the month of January in the northern part of Bangladesh. The minimum temperature was 8.4°C (47.12°F). In many parts of the country, the minimum temperature in January was not so low. For example, in Cox’s Bazar which is situated in the southwest, the minimum temperature was observed to be 14.9°C (58.82°F). So it is suggested to use values from particular area while designing structure when significant difference is observed. We used the lowest minimum temperature found in the northern part (47.12°F) [1].

The difference between maximum and minimum temperature = 94.64°F – 47.12°F = 47.52°F = 48°F.
Thermal loads (48°F) were assigned as uniform temperature change at all slab shell elements and as frame loads on beams and columns of all stories.

2.5. Parametric study
The various cases considered in the research are presented in Table 3.

| Case no. | Bay dimension (ft x ft) | No. of bays in short direction | Building height (ft) | Load combinations | Remarks |
|----------|-------------------------|-------------------------------|---------------------|------------------|---------|
| 1        | 20 x 20                 | 1                             | 56 (6-story)        | 1.4D + 1.7L      |         |
| 2        | 25 x 25                 | 1                             | 56                  | 1.4D + 1.7L      |         |
| 3        | 30 x 30                 | 1                             | 56                  | 1.4D + 1.7L      |         |
| 4        | 20 x 20                 | 3                             | 56                  | 1.4D + 1.7L + 1.0T | Change of bay number in short direction |
| 5        | 20 x 20                 | 1                             | 56                  | 1.4D + 1.7L + 1.0T |         |
| 6        | 25 x 25                 | 1                             | 56                  | 1.4D + 1.7L + 1.0T |         |
| 7        | 30 x 30                 | 1                             | 56                  | 1.4D + 1.7L + 1.0T |         |
| 8        | 20 x 20                 | 1                             | 56                  | 1.0T             |         |
| 9        | 25 x 25                 | 1                             | 56                  | 1.0T             |         |
| 10       | 30 x 30                 | 1                             | 56                  | 1.0T             |         |
| 11       | 20 x 20                 | 1                             | 56                  | 18 load comb. from BNBC (without temperature) | Including shear wall |
| 12       | 20 x 20                 | 1                             | 56                  | 18 load comb. from BNBC (with temperature) | Including shear wall |

3. Results and discussions
In this section the results of the thermal study conducted on the twelve different reinforced concrete frame structure models are presented. The results from the first set of models with varying lengths were used to find an allowable maximum spacing of expansion gap based on maximum permissible top deflection. The results from the second set of models with shear wall on both ends were used to show change in axial loads in beam and column for both with and without temperature cases. The results from the third set of models with different number of bays in short direction were used to compare between single bay and triple bay structures under the application of thermal load. In the end the change in requirement of rebar percentage with increasing length was presented for load combination 1.4D+1.7L+1.0T.

3.1. Determination of allowable deflection limit as per BNBC 2006
The maximum permissible computed deflection for RC framed structure is \([L/480]++\) with complying some other conditions \([4,5]\). Current study incorporates \((L/500)\) to compute the maximum permissible deflection where ‘L’ means total height of building structure in ‘inch’.

a) Permissible maximum top deflection for 6-story (56 ft) building = \((56 \times 12)/500 = 1.344\) inch

3.2. Maximum spacing of expansion gap based on maximum permissible deflection
For a 6 story building, bays of three different dimensions were modeled up to 900 ft height and their top deflection values in x-direction were observed with the increasing length. It was seen that for a load combination of 1.4D + 1.7L + 1.0 T, deflection increased linearly and significantly with the
A gradual increase in building length for all bay dimensions. But for a load combination of $1.4D + 1.7L$, the values of deflection were almost constant with increasing length. In Table 4, the change in top deflection in x-direction with increasing length is presented for both with and without temperature cases.

Table 4. Variation of top deflection of single bay 6 story structures with increasing length.

| Load combination | Building Length ft | Top deflection in X-direction inch |
|------------------|--------------------|-----------------------------------|
|                  |                    | 20 x 20 bay | 25 x 25 bay | 30 x 30 bay |
| $1.4D + 1.7L$    | 100                | -0.0022350  | -0.0035670  | -0.0096170  |
|                  | 200                | -0.0039790  | -0.0061960  | -0.0166940  |
|                  | 300                | -0.0045296  | -0.0086070  | -0.021806   |
|                  | 400                | -0.0068720  | -0.0107800  | -0.025482   |
|                  | 500                | -0.0080440  | -0.0144750  | -0.028718   |
|                  | 700                | -0.0099710  | -0.0174660  | -0.0096170  |
|                  | 900                | -0.0114810  | -0.0187540  | -0.0166940  |
| $1.4D + 1.7L + 1.0T$ | 100              | 0.1567530   | 0.1558240   | 0.3257830   |
|                  | 200                | 0.3138680   | 0.3123180   | 0.6533320   |
|                  | 300                | 0.4286790   | 0.4689630   | 0.934729    |
|                  | 400                | 0.6285400   | 0.6257670   | 1.169745    |
|                  | 500                | 0.7861400   | 0.9398960   | 1.405247    |
|                  | 700                | 1.1013870   | 1.2547490   | 0.3257830   |
|                  | 900                | 1.4136670   | 1.4120960   | 0.6533320   |

For all bay dimensions, the values of deflection in x direction exceeded the maximum permissible deflection limit for 6 story (56 ft) at 900 ft. So the allowable maximum expansion gap spacing lies somewhere below 900 ft which was later determined by interpolating from graphs. For maximum permissible deflection for a 6 story building (1.344 inch), the corresponding length of building was determined. This length will represent the maximum allowable expansion gap spacing. In Figures 3, 4 and 5, deflection in x-axis vs length of the building graphs are shown respectively for 20x20, 25x25 and 30x30 bay dimensions.
After interpolating each graph from Figure 3 to Figure 5, spacing values that can be allowed for different bay dimensions are as follows:

i) 20 ft x 20 ft bay Maximum Allowable Expansion Gap Spacing = 855 ft
ii) 25 ft x 25 ft bay Maximum Allowable Expansion Gap Spacing = 797 ft
iii) 30 ft x 30 ft bay Maximum Allowable Expansion Gap Spacing = 861 ft

Thus it can be concluded that
- for typical bays of dimensions about 20’x20’, 25’x25’ and 30’x30’,
- for a uniform temperature change of 48°F in context of Bangladesh’s average temperature data,
- for a 6-story building,
- for beam dimension 20x10 (inch x inch) and column dimension 15x15 (inch x inch),
- for a single bay structure,
- for a load combination of 1.4D + 1.7L + 1.0T,

A reinforced concrete slab can be extended up to about 750 ft without providing any expansion gap. For a longer slab, it will be necessary to provide expansion gap to minimize the effect of thermal expansion and contraction.

3.3. Comparison of beam and column axial loads of structures with shear wall due to temperature load

Building layout with rigid shear walls at ends could drastically change the scenarios. For this purpose, a six-story, 100ft long structure having shear wall at both ends were analyzed with and without temperature effect. Comparison for a six-story, 100ft long structure with shear wall (Case no. 11,12 from Table 3) for 18 load combinations as per BNBC [4] with & without temperature is shown in Figures 5 and 6 respectively.
Comparison between Figure 6 and 7 is shown in Table 5.

**Table 5. Comparison of axial force due to temperature in structural members.**

| Structural member       | Change in axial force                                                                 |
|-------------------------|---------------------------------------------------------------------------------------|
| Exterior columns        | Application of temperature loads resulted in a significant increase in the value of axial force. At story 5, axial force increased by about 20 times. At story 2, axial force had the highest value and the increase with temperature load was about 5 times. |
| First interior columns  | The percentage of increase was lesser than the exterior columns. At story 5, axial force increased by 6.5 times only with application of temperature load. |
| Second interior columns | The percentage of increase was almost negligible. At story 5, axial force increased by 1.03 times only with application of temperature load. |
| Beams                   | Axial force was observed only in story 1 when temperature load was not applied. Whereas when temperature load was applied, a constant axial force 190.08 kip was observed to be acting on the beams of all floors. |

3.4. **Comparison of top deflection between single bay and triple bay structures**

For 20’x20’ bay dimension and a 6 story (56ft) building, comparison between single bay and triple bay structures show that top deflection of exterior columns do not change significantly when the bay number was increased in the short direction from 1 to 3. So, for a triple bay structure, we can use the same allowable expansion gap spacing as the single bay structure.

3.5. **Observation of change in reinforcement requirement**

Observing change in reinforcement due to increasing length for load combination 1.4D+1.7L+1.0T, we saw that rebar percentage increases in each beam but the change becomes negligible in higher stories. In lower stories as in story 1, it has significant change and the value increases by .15% for each 150ft increment. In case of column, the change is significant and in 900ft the columns of story 1 and story 2 fails due to over estimation of reinforcement bars. In story 1, from 210ft to 420ft rebar percentage becomes 1.81 times (1.68% to 3.04%) in external columns. In story 3,4,5,6 there is almost no change except in the structure of length 900ft.
4. Conclusions

Building with significant length that lacks properly placed expansion joints could result in undue stresses in building elements. High change of temperature in fact has large impacts in structures. In this study, it was a small scale endeavour to work on the effects of temperature change and show the outcomes due to change in temperature in context of Bangladesh. The present research work started with an aim to determine a building length without expansion gap that can be safely constructed. To determine allowable building length without expansion joint various studies have been done using finite element modelling with ETABS software. There were some important outcomes that have been observed from the present study.

From the results obtained in this study, the following conclusions can be drawn:

- From the analysis, it was found out that a reinforced concrete structure can be extended up to around 750ft without any expansion gap under conditions similar to that presented in the study. For structures longer than 750ft, it will be necessary to provide expansion gap to minimize the effect of thermal expansion. For this case, only gravity loads and temperature load were considered.
- If shear wall is used to restrain a RCC structure under the effect of temperature load, significant change in axial force of columns is observed as compared to a structure without shear walls. Increasing the length of such a structure results in the increase of axial force of exterior columns at all story levels after a certain length. Temperature effect in such a case could be quite onerous on the structure.
- It was observed that rebar percentage increases with the increasing length in both beam and column but the percentage decreases with increasing story numbers. Columns fail due to excessive demand of rebar in structures having length of about 900ft under temperature load. So it can be said that at around 750ft length, expansion gap is required under mentioned conditions in section 3.5.
- With increasing length, top deflection increases in the same direction uniformly due to temperature load.

References

[1] Bangladesh Meteorological Department <http://bmd.gov.bd>
[2] ACI Committee 224 2001 Joints in concrete construction (US: American Concrete Institute)
[3] ACI Committee 209 1997 Prediction of creep, shrinkage, and temperature effects in concrete structures (US: American Concrete Institute)
[4] House Building and Research Institution 2006 Bangladesh National Building Code (Bangladesh: Ministry of Housing and Public Works)
[5] ACI Committee 318 2005 Building Code Requirements for Structural Concrete (ACI318-05) and Commentary (ACI 318R-05) (Farmington Hills: American Concrete Institute) p 430