Design of Expansion Joints in Parking Structures

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Whether an expansion joint should be installed in a parking structure is one of the questions discussed during the design phase. An expansion joint is introduced by dividing a structure into two or more segments and then providing an opening, or a gap, between the adjacent structural segments starting from ground level up to the roof. The purpose of an expansion joint is to reduce build-up of volume change (VC) stresses and the associated structural distress (*Figures 1* and *2*). An expansion joint is considered a necessary evil because omitting an expansion joint where it is needed creates a risk of structural distress. On the other hand, installing an expansion joint when it is not needed increases initial construction cost and adds to the maintenance costs of the facility. Therefore, optimizing the expansion joint design is critical for success of a project, particularly for exposed structures such as parking facilities.

The expansion joint design involves three steps. The first step is the threshold question of whether an expansion joint is needed in the structure. If so, determine the location(s) or spacing of the expansion joints. Next, the gap width of the joint (*Figure 3*) is determined. Third, type of hardware to bridge the gap is specified, considering the gap width, type of use, loading and environmental exposure.

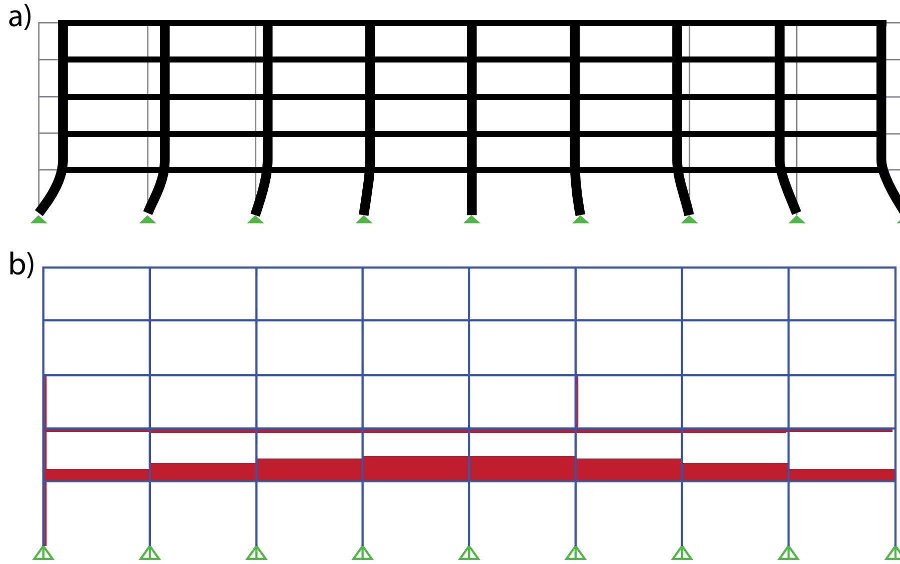

Figure 1: (a) Deformed shape and (b) Tensile Force build-up in Floor Diaphragms of a symmetric frame due to a thermal drop.

Historical Review

The issue of whether a structural footprint should be split into segments with an expansion joint between them was first addressed by the Federal Construction Council (FCC), which developed the guidelines based on measurements recorded in 1943 in nine buildings. For rectangular buildings, FCC required the expansion joint spacing criteria to consider two factors: design temperature and column base fixity, as shown in *Figure 4 (page 14)*. Chrest *et al.*, in their book on parking structures, recognized the difference in behavior of precast and post-tensioned concrete structural systems and proposed that expansion joints in post-tensioned parking structures located in the Midwest should be spaced at 200 feet (61 meters) maximum; however, if the floor diaphragm had a pourstrip, the spacing could be increased to 275 feet (84 meters). Subsequently, the Post-tensioning Institute (PTI) published its expansion joint guidelines for moderate temperature regions, as shown in *Figure 4 (page 14)*. However, the ACI-224 report terms the approaches as "rules of thumb." In author's opinion, the rules serve as a starting point. However, the rules have implied assumptions which need to be articulated. On one hand, numerous structures have been built that exceed the prescribed spacing limits and are performing well (e.g. see *Figure 5, page 14*); however, there may be other structures that may meet the criteria and yet not perform well.

Expansion joint spacing depends on several factors such as the stiffness and location of lateral force resisting system (LFRS), weather exposure conditions and, in the case of pre-topped double tee construction, on connection deformability between the double-tees as well. It is well known that the VC movement increases with the distance from the center of rigidity. For structures with symmetrically located LFRS, the VC movement is symmetric (*Figure 1*) and for structures with asymmetrically-located LFRS, the VC movement is also asymmetrical (*Figure 2*).

Historically, most parking structures are built using concrete, and are open and unheated. As such they are subjected to creep, shrinkage and temperature (C-S-T) effects. Further, in the case of post-tensioned structures, floor shortening caused by pre-compression adds to the C-S-T effects in causing structural movement in parking structures. The four factors are jointly known as the *VC effects*. The restraint to the VC-induced movement causes stresses that manifest in cracks, leaks and premature deterioration in concrete structures. To design for the VC effects, ACI-318 requires that design be based on a "realistic assessment" of such effects occurring in service. However, it leaves the assessment process to the design professional. Further, the ACI-318 commentary states that, where LFRS provides "significant restraint" to shrinkage and temperature movements, it may

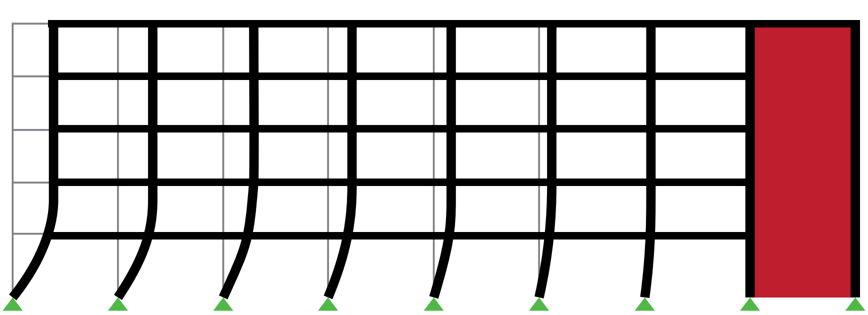

Figure 2: Deformed shape of a coupled frame-shearwall subjected to a thermal drop. The maximum displacement is at the outermost column, located farthest from the shearwall.

be necessary to increase the amount of slab reinforcement required to control cracking; however, it does not define what "significant restraint" is. The issue then becomes: How should a design professional realistically assess whether the restraint is significant?

Significant Restraint

In order to define "significant restraint" quantitatively and realistically, the author measured the VC movements in several parking garages in the Chicago area over several years. The VC measurements were recorded during winter and summer months, with temperature ranging from -6 °F to 74 °F (-21°C to 23 °C). A detailed analysis of the results was published in the *ACI Structural Magazine*. As a summary, the observed VC data showed that the diaphragms in parking facilities do not move freely, but that their movement is restrained. The degree of restraint depends upon the LFRS and the type of construction. The degree of structural restraint for a monolithic diaphragm of length L subjected to thermal differential ΔT can be determined by the equation:

$$\Delta L = M.\ e_{th}.\ L.\ \Delta T \qquad \text{Equation 1}$$

where e_{th} is the coefficient of thermal expansion. For concrete, it is approximately 7.5 x 10^{-6} in./in./F°. The M-factor, or the movement factor, is defined as the ratio of observed diaphragm movement and the calculated unrestrained movement under volume changes. The M-factor values range from 0.0 and 1.0, and indicate a structure's intrinsic capability to move under volume changes. When a diaphragm is free to move under volume changes, its M-factor will be unity. On the other hand, a diaphragm that is fully restrained by a rigid LFRS, such as a box system, will have an M-factor of zero. Post-tensioned diaphragms show different characteristics than factory-topped double-tee diaphragms due to the presence of joints in the precast construction.

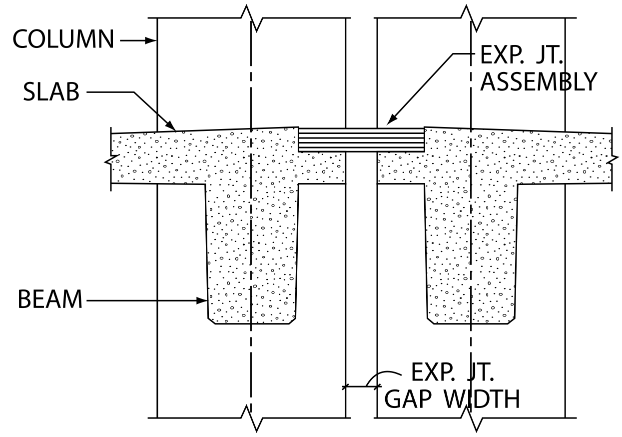

Figure 3: Double column expansion joint in cast-in-place concrete construction.

Based on the recorded data, it was determined that a monolithic diaphragm works well when its M-factor is at least 0.8. For post-tensioned and field-topped precast parking structures, the M-factor serves as a useful index in quantifying and predicting the restraint cracking in a structure. The M-factor of 0.80 means that a structure moves 80% of the total unrestrained movement, with remaining 20% movement consumed in the structural restraint. The 80% movement level also indicates the degree of restraint post-tensioned structures may tolerate while performing reasonably well. If a structure's LFRS is designed with its M-factor between 0.80 and 1.0, it would exhibit minimal restraint cracks. However, if the LFRS is stiff so that the diaphragm's M-factor falls below 0.80, say to 0.70, the facility is likely to exhibit noticeable restraint cracking. Similarly, an extremely stiff structure having an M-factor of zero or near-zero would be most prone to restraint cracking. For regions that have a colder climate than Chicago, using the M-factor of 0.80 as minimum may not be prudent. In such cases, the structure needs to be more flexible and so the cut-off point should be increased, say to 0.90.

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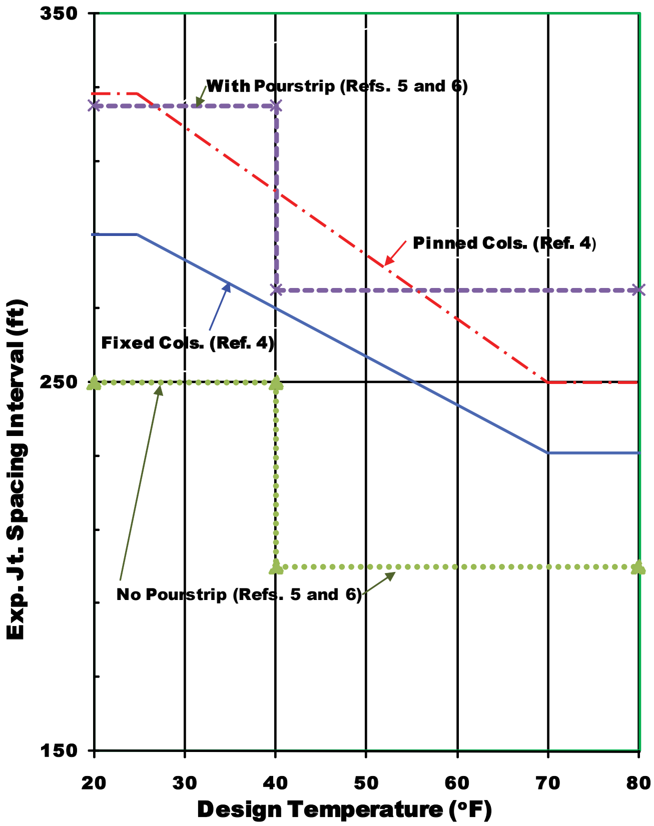

Figure 4: Expansion Joint Spacing Criteria Plot (1 foot = 0.304 meters)

Figure 5: A post-tensioned parking structure in Elizabeth, Indiana with expansion joint spaced at 334 feet (104 meters) apart. (Engineer: Walker Parking Consultants)

In order to optimize the expansion joint spacing, the criteria in *Figure 5* should be used as a first rudimentary step, and then the LFRS layout and stiffness should be adjusted so that the M-factor is within its acceptable limits.

Gap width

For a structure located in a seismic zone, the expansion joint gap needs to be wide enough to avoid seismic pounding while incorporating the VC effects. Generally, International Building Code's (IBC) ABS and SRSS methods are used to compute seismic separation between adjacent structures. However, an optimum way to size the expansion joint is to use Professor Kasai method. The method takes into consideration the inelastic deformation as well as frequencies of adjacent parts of the building.

$$u_{rel} = \sqrt{u_A^2 + u_B^2 - 2\rho_{AB}\,.u_A\,.u_B} \quad \text{Equation 2}$$

where u_A and u_B are the peak drift values and ρ_{AB} is the cross-correlation coefficient and reflects vibration phase between the two structural units separated by an expansion joint. For two systems having equal damping ratios, ρ_{AB}, is given by:

$$\rho_{AB} = \frac{8\xi^2\,(1+T_B/T_A)(T_B/T_A)^{3/2}}{[1-(T_B/T_A)^2]^2 + 4\xi^2\,(1+T_B/T_A)^2(T_B/T_A)}$$

Equation 3

where T_A and T_B are the fundamental periods of the adjacent structural units A and B, respectively, and ξ is the average effective damping ratio of the structural units A and B.

The method was explained in the 2009 *PTI Journal* using a 5-story structure as an example.

Joint Assembly

Selection

The type of assembly should be selected considering the gap width, type of traffic loading expected and the prior performance history of the assembly under similar projects. In parking decks, where vehicular traffic is anticipated, the issue of snow plow trucks crossing the expansion joint should be considered. In addition, treatment of work at and around expansion joints and the responsibilities of parties involved in the work, need to be defined in a pre-construction expansion joint meeting.

Installation

Expansion joint installation is a specialty, and project documents should emphasize the need for a heightened care required to complete the task. The contract documents should require that the contractor call a pre-construction meeting of parties involved in performing the work at and around the expansion joints, to educate all involved parties about their responsibilities in installing the expansion joints and to ensure that the following conditions are met:

1) The expansion joints in the floor should be straight and should align, without offset, with expansion joints in vertical planes such as double columns and walls.
2) The expansion joint separation should not be used as a place for tolerance build-up from other construction activities.
3) The expansion joint gap should have a consistent width throughout. If the gap is cast at a temperature other than the specified mean temperature, and/or post-tensioned concrete is used, adjustment in the gap width may be needed to ensure that the specified joint has the specified movement capability. A design example published in the 2009 *PTI Journal* illustrates the design steps needed.
4) Forms should be strong with tight joints so as to allow concrete next to the forms to be thoroughly vibrated to ensure proper consolidation, to prevent seepage of concrete and irregularities in joint shape, and to avoid voids within concrete or on concrete surface.
5) The forms should be removed promptly after initial curing of concrete to prevent them from being squeezed or becoming dislodged due to the joint movement.
6) Once formed, the expansion joint gaps in the decks and floors need to be protected from damage by construction traffic throughout their length. At crossing points, joints should be protected with plates or ramps.
7) Joints in the walls should be free of mortar protrusion, masonry ties, protruding shelf angles, and other obstructions that might hinder the movement or obstruct installation of the expansion joint system.▪

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