# EFFECTIVENESS OF EXPANSION JOINTS PROVISION FOR TEMPERATURE AND LOAD IN STEEL STRUCTURES

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## ABSTRACT

The provisions of expansion joints for loads and temperature in steel structures have been evaluated on the formulations given in major and current steel design codes. Results indicate that as the modules or lengths subject to expansion increases and with increasing temperature, there is a drastic reduction in the safety of the joints. Although the joints appear to be practically safe at the levels of loads and temperature investigated, yet it is advisable that lower expansion widths be provided in order to increase their safety and effectiveness so as to alleviate secondary effects as may be induced by skew, racking and temperature changes, for examples, especially in bridge superstructures.

**Keywords**: movement joints, steel structures, temperature, structural safety and system lengths.

## 1.0 INTRODUCTION

An expansion joint is a term used to describe an assembly designed to safely absorb the heat induced expansion and contraction of various construction materials in order to absorb vibration, or to allow for movements due to ground settlement or earthquakes (Dexter et al 2002). Dexter et al (2002) also noted that these expansion joints are commonly found between sections of sidewalks, ridges, railway tracks, piping systems and other structures such as steel buildings and concrete blocks. In a more simple sense, an expansion joint can be defined as a gap left between adjacent parts or surfaces to prevent failure when they expand under heat. However, with respect to steel structural buildings expansion joints refer to isolation joints provided within a building to permit separate segments of the structural frame to expand and contract in response to temperature changes without adversely affecting the building structural integrity or serviceability (NRC, 1974).

In general, expansion joints are usually placed at strategic points in construction, making it possible for sections to expand and contract slightly without jeopardizing the stability of the entire structure (Wai-Fah and Chen, 2000). Regardless of the type of structure in which the expansion joints is being used, they should be placed at key locations to allow for expansion and contraction as weather changes (Wai-Fah and Chen, 2000). All structures move to some extent; movements may be permanent and irreversible or short term and reversible (Davidson and Owens, 2003). Expansion and contraction are movements that are continuous throughout the life span of a structure. The effects can be significant in terms of the behaviour of the structure, its performance during its life span and the continued integrity of the material from which it was built (Davidson and Owens, 2003). Movement can arise from a variety of sources, for example; (1) environmental factors:- thermal expansion and contraction due to temperature change, humidity, and wind induced; (2) material properties: such as creep and shrinkage; and (3) loading: axial and flexural strains, impact, braking, traction, centrifugal force, etc.

The movement of a structure are not in themselves detrimental; problem arise when movements are restrained, either by the way in which the structure is connected to the ground or by surrounding elements such as claddings, adjacent buildings or other fixed or more rigid items (MacGinley and Ang, 1998). With respect to movement of structures BS 8007 (1987) sees expansion joints as types of movement joints, intended to accommodate movement (expansion and contraction) between adjacent parts of a structure without offering any resistance. The need to provide for these movements of structures and at the same time provide an adequate design that will carry out its intended purpose for its intended life time highlights the relevance of expansion joints in structures. Structures should be provided with movement joints to avoid unacceptable cracking (BS 8007, 1987).

When steel structural elements are subjected to temperature changes, as a result of seasonal changes, or as a result of the nature or use of buildings in which the member is situated (for instance steel structural frame located in a heating room), they expand and contract intermittently (Dexter et al, 2002). The expansion occurs during the hot season or when the heating element is on, while contraction occurs during the cold seasons or when the heating element is removed and the structure is allowed to cool (Dexter et al, 2002). In steel structures the role of expansion joints is that of (a) allowing for heat induced contraction and expansion occurring intermittently during seasonal changes in order to ensure that the structure remains stable to carry out its intended purpose for its intended life span (Dexter et al, 2002); (b) allowing for movement that may occur to the structure as a result of loading or as a result of ground settlements or earthquakes (BS 8007, 1987).

This paper presents a study by a suitable optimization technique, the effectiveness of expansion joints provision for temperature and load in steel structures using steel bridges as case study. The purpose of this study is to achieve the following objectives; (i) reveal the effectiveness/relevance of expansion joint provision in steel structures as in EC3 (2004), BS5950 (2000) and AISC (2005); (ii) investigate the direct effect of expansion joints provision for temperature and load in steel structures; (iii) suggest where applicable reliable evaluation criteria for assessing the effectiveness of expansion joints provision for temperature and load in steel structures.

## 2.0 BACKGROUND OF EXPANSION JOINTS IN STEEL STRUCTURES

The concept of expansion joint provisions is utilized in many different types of structures. Even walls composed of construction materials like brick or concrete blocks are routinely fitted with expansion joints today, because it helps minimize cracking in the veneer wall. Although in concrete block constructions the term is known as control joints. Apart from bridges, rail tracks, pipes, and other structures, where the need for expansion joints is significant, all buildings move and most buildings have, or should have joints to accommodate dimensional changes. The use of expansion joints in buildings is a controversial issue (Fintel, 1985). In concrete constructions, some experts have argued that expansion joints spacing should be as low as 9.144m (30ft), while others consider expansion joints as entirely unnecessary. In steel structures a spacing of 60.96m (200ft) is normal according to Fintel (1985).

Throughout the year, steel structures, building faces, concrete slabs, etc, will expand and contract due to warming and cooling through seasonal variations, or due to other heat sources. Before expansion gaps were built into these structures, they would crack under the stress induced (Fisher, 2005). Thus it has been noted by Fisher (2005) that in the most basic sense, the need for an expansion joint in a structure depends on the consequence of not having an expansion joint. In the last few decades integral bridges were fitted with expansion joints and bearings to separate the superstructure from the substructure and the surrounding soil. This was to allow for vertical movement that may occur when the bridge is loaded excessively (Obrien and Keogh, 1999). Obrien and Keogh (1999) have suggested that when a bridge is subjected to loads within the design load of the structure, expansion joints need not be provided to cater for loads. This suggestion is investigated and this work focuses on expansion joints that allow structures to move horizontally as a result of temperature variations or changes in the structure when it is subjected to design loads.

Steel structural frames are not made up of a single steel member alone, rather different structural elements are assembled to form a unit. In steel framed buildings the skeleton consists of lines of continuous vertical stanchions to which horizontal steel beams are attached. The beams support the roof and floors of the building and also the walls of which panels are built in general from floor to floor. A similar assembly of high strength steel elements is found in steel bridges. Since a steel frame work is made up of an assembly of individual steel elements, the framework must therefore be capable of, safely and independently, sustaining the whole dead load of the structure in addition to live loads imposed on the structure (Baker, 1960). In general the entire framework must be able to, as a unit, safely transfer resultant loads to the ground.

Expansion joints are usually placed in bridges to accommodate relative movements between superstructure segments of the bridges and movements between superstructures and abutments as a result of thermal expansion and contraction, superstructure settlement, live load, and other causes (Dexter et al, 2002). Expansion joints can be broadly grouped into two categories (Dexter et al, 2002), namely; (a) Open expansion joints, which are joints that have no seal e.g. finger or tooth joints. These joints allow water and debris to pass through the deck joint. This deck drainage often leads to problems such as corrosion of bridge superstructure elements near the joint; (b) Closed or sealed expansion joints refer to expansion joints assembly in which the expansion gap is sealed with a sealant that will permit expansion without offering any restraint to the movement. Sealed expansion joints offer protection to the underlying bridge superstructures by eliminating drainage through the deck joint. If a sealed joint remains effective, this protection against corrosion extends the useful life of both steel and concrete bridges, and reduces the need for coatings as well as maintenance replacements. For example weathering steel could be used under the joint without additional coatings, provided that the expansion joints can be relied upon to remain sealed.

But the documentations on the types of expansion joints are not specific on steel structures. The following types of expansion joints however exists (NDOT, 2008): (a) modular expansion joints, which includes (i) single support bar system; (ii) multiple support bar system; (b) single cell expansion joints, which includes (i) compression seals; (ii) strip seals; (iii) bolted joints; (c) finger expansion joints, which includes (i) trough assemblies; (ii) galvanized steel; (iii) stainless steel; (d) reinforced neoprene; (e) catch basins; and (f) cover plate assemblies.

The application of these types of expansion joints depends on factors, such as the expected temperature change, movement, skew, type of structure in which they would be used, etc. In bridges expansion joints may be classified with respect to the amount of movement expected. The joints may be classified as; small movement joints, medium movement joints, and large movement joints. The various types of joints are fully described (AASHTO LRFD-MNDOT, 2008).

The need for thermal expansion joints in buildings may be determined initially on empirical basis. If results are deemed by the designer to be too conservative or if empirical method is not comprehensive to be applicable to the type of structure under investigation, a more precise analysis should be undertaken. In either case, NRC (1974) has given the criteria for the determination of expansion joints using the empirical or analytical methods, while taking into consideration the prevailing conditions of loads and temperature and influencing factors such as length and type of structural frame, support conditions, type and use of building, materials of construction, associated temperatures environment, etc.

Although buildings are often constructed of flexible materials, roof and structural expansion joints are required when plan dimensions are large. It is not possible to state exact requirements relative to distances between expansion joints because of the many variables involved, such as ambient temperatures during construction and the expected temperature range during the life of a building. However visualizing how the structure and its parts will move under temperature change is helpful in locating expansion joints. The National Roofing Contractors Association (NRCA, 2001) gives the following recommendations for the location of roof expansion joints: (i) where steel framing, structural steel, or decking change direction; (ii) where separate wings of L, U, and T shaped buildings or similar configurations exist; (iii) where the type of decking changes; for example, where a precast concrete deck and a steel deck abut; (iv) where additions are connected to existing buildings; (v) at junctions where interior heating conditions change, such as a heated office abutting an unheated warehouse, canopies, etc; and (vi) where movement between walls and the roof deck may occur.

For bridges, the AASHTO LRFD (2004) design manual states that the number and location of expansion joints should be determined based on maximum joint opening of approximately 100mm (4 inches) at the ends of the bridge. When joint openings exceed 100mm two options are available (MDOT, 2007): (a) preferably provide additional joints at the piers to split the superstructure into segments; and (b) on rare occasions provide modular expansion joints at bridge ends only.

But the size of an expansion joint is determined from the basic thermal expression for the material used for the frame in the structure (Fisher, 2005). Thus,

$$\Delta = \alpha L \Delta_{\theta} \tag{1}$$

Where, $\alpha$ = the coefficient of linear expansivity and, $\alpha = 0.0000065$ for steel superstructures in the AASHTO LRFD (2004) standard specifications; L = the length subject to the temperature change, and $\Delta_{\theta}$ = temperature change. However, $\Delta_{\theta}$ is based on the design temperature change, that is, $(T_w - T_m)$ or $(T_m - T_c)$, $\Delta L$ = change in length due to temperature. Note that the change during the construction cycle, $(T_m - T_c)$, is usually the largest; where, $T_m$ is defined as the mean temperature during the normal construction season in the locality of the building. The normal construction season for a locality can be defined as that contiguous period in a year during which the minimum daily temperature equals or exceeds 0˚C (32˚F). Also, $T_w$ is the temperature exceeded, on the average, only one percent of the time during the summer months (similar to dry season in the tropics) in the locality of the building and $T_c$ is the temperature equaled or exceeded, on the average, 99% of the time during the winter months (similar to wet season in the tropics).

Thermal expansion has been defined (Obrien and Keogh, 1999) as the tendency of a matter to change in volume in response to a change in temperature. When a substance is heated, its constituent particles begin moving and become active thus maintaining a greater average separation (Obrien and Keogh, 1999). Materials which contract with increasing temperature are rare; this effect is limited in size, and only occurs within limited temperature ranges. The degree of expansion divided by the change in temperature is called the material's coefficient of thermal expansion and generally varies with temperature. The coefficient of expansion for common engineering solids usually do not vary significantly over the range of temperatures where they are designed to be used, so where extremely high accuracy is not required, calculations can be based on constant average value of the coefficient of expansion.

For steel structures the thermal coefficient of expansivity ($\alpha$) is $6.5 \times 10^{-6}$ (NASCC, 2005). For solid materials with significant length e.g. steel rods, an estimate of the amount of thermal expansion can be made using the following strain relationship;

$$\epsilon_{thermal} = \frac{L_{final} - L_{initial}}{L_{initial}} \qquad (2)$$

where, $L_{initial}$ = the initial length before the change of temperature and $L_{final}$ = the final length recorded after the change of temperature. For most solids, thermal expansion relates directly with temperature. Thus, the change in either the strain or temperature can be estimated by (Fisher, 2005):

$$\epsilon_{thermal} = \alpha \Delta_T \qquad (3)$$

where, $\Delta_T$ refers to change in temperature; $\Delta_T = (T_{final} - T_{inintial})$; and $\alpha$ = the coefficient of thermal expansion in inverse Kelvins. Thermal expansion occurs as a result of temperature change and this causes the individual members of a steel structure to expand in length, and hence the need for expansion joints.

## 2.1 DESIGN OF EXPANSION JOINTS IN STEEL BRIDGES

Specifications have been given by various authorities for total movements, gap width and depth of expansion joints. However, these are mainly based on rule of thumb or just mere recommendations without actual engineering analysis. But some scientific estimation has been suggested. Mark et al (2008) have suggested that the thermal movement (in inches) shall be:

$$\Delta_T = \alpha L\,(T_{maxDesign} - T_{minDesign}) \qquad (4)$$

where; $\alpha$ = coefficient of thermal expansion, $1.24 \times 10^{-5}$ /ºC for steel structures; L = tributary expansion length. Distance from the expansion joint to the point of assumed zero movement; $T_{maxDesign}$ = maximum design temperature; $T_{minDesign}$ = minimum design temperature. The coefficient of thermal expansion for steel in metric unit is $\alpha = 6.5 \times 10^{-6}$ mm/$^{o}$C.

The total design movement of steel bridges can be taken as estimated design thermal movement (Mark et al, 2008). This is due to the fact that for steel girder structures creep and shrinkage effects are minimal. This is in contrast to concrete bridges where it will be necessary to consider the effects of creep and shrinkage (Mark et al, 2008). In this case the estimated design thermal movement may be increased by 15%, or simply taken as 115% of the estimated thermal movement (Mark et al, 2008). For expansion joints in concrete bridges, the total design movement is given as, Total design movement = $1.15\Delta_T = 1.15[\alpha L(T_{maxDesign} - T_{minDesign})]$ (5)

Also, according to Dexter et al (2002) **e**xpansion joints selection in bridges should be based on the following factors ( ); (i) expansion joints must fully accommodate structural movements without exceeding the manufacturer's recommended clear span at deck surface level when at maximum opening; (ii) they must provide a proper anchorage and structural capacity to resist anticipated loads; (iii) in steel bridges, they must have acceptable riding surface; (iv) be reasonably quiet and vibration free; and (v) must facilitate inspection, maintenance, repair, removal and replacement, and must be corrosion resistant, etc.

In general expansion joints are selected based on the magnitude of movement anticipated, or joint opening (Mark et al, 2008). It is important to select the appropriate type of expansion joint for the appropriate situation. One point that must not be forgotten while doing so is the overall stability of the structure. The British and Euro codes for steel design state that to provide practical level of robustness against effect of incidental loading, all structures including portions between expansion joints should have adequate resistance to horizontal forces. It is also stated that all structures including portions between expansion joints should have sufficient sway stiffness, so that vertical loads acting with lateral displacement of the structure do not induce excessive secondary forces or movement in the members or connections.

Expansion joints, when properly designed and installed extends the useful life of the bridge. However, their lifespan is much shorter than that of the bridge and they tend to deteriorate with traffic and cause bumpiness of riding. Thus, as a result of this, they are potential source of trouble (Chatterjee, 2003). Therefore they should be adequately provided for and installed.

## 3.0 MATERIALS AND METHODS

### 3.1 BASIC EXPANSION JOINTS DESIGN CONCEPT

The basic concept in the provision of longitudinal expansion joints in steel structures or as a matter of fact, all other structures requiring expansion joints, is to do so based on the anticipated thermal movement of the structure (Mark et al, 2008). The total anticipated movement after sufficient consideration is given to other factors such as, racking demands, and skew etc. is used as basis for utilization of a particular type of expansion joint (Mark et al, 2008). The procedures recommended for the design and selection of expansion joints to cater for movement in steel structures are noted in Mark et al (2008). The gap width requirements for steel structures are stochastically evaluated with due consideration for longitudinal movement, skew and racking, when the steel deck lengths are 36.0m and 76.2m in this presentation.

### 3.2 DESIGN PROCEDURES

The following procedures are recommended in the design and selection of expansion joints provision to cater for longitudinal movement in steel structures (Mark et al, 2008):-

1. **Estimation of Design Thermal movement:-** A common approach in determining the design thermal movement which is as a result of temperature change is to utilize the expression given in Equation (4).
2. **Consideration of Skew:-** After determining the design thermal movement using Equation (4) the next step is to consider skew angle. This is done by multiplying the design thermal movement by the cosine of the skew angle (Mark et al, 2008). If the angle of skew is θ, then Equation (4) is modified as follows:

$\Delta_{TS} = \alpha L\ (T_{maxDesign} - T_{minDesign}) \cos\theta$ (6)

$\Delta_{TS} = \Delta_T \cos\theta$ (7)

where; $\Delta_{TS}$ is the design thermal movement considering skew. The resulting movement is used as a criterion for selection of a type of expansion joint for the design.

3. **Consideration of Racking :-** The maximum allowed racking is 20% of the movement range of the selected expansion joint (AASHTO LRFD-MNDOT, 2008). For a strip seal for instance, the movement range is between 25.4mm (1inch) and 101.6mm (4inches). The maximum allowable racking R is:
   $R = 0.20UB$ (8)
   where; R is allowable racking, and UB refers to upper boundary of movement range for a particular type of joint.
   Hence for a strip seal, R = 0.20 x 101.6 = 20.32mm and this is normal to the seal.
   The corresponding movement parallel to seal is then given as;
   $MVT_{par} = \frac{R}{\sin\theta}$ (9)
   For a strip seal with skew angle of 30º for instance,
   $MVT_{par} = \frac{20.32}{\sin 30} = 40.64\text{mm}$
   The corresponding temperature change is given by the following relationship
   $T_\theta = (T_{maxDesign} - T_{minDesign}) \times \frac{MVTpar}{\Delta T}$ (10)
   where, $T_\theta$ , temperature change that corresponds to the parallel movement $MVT_{par}$.
   The installation temperature range can be obtained by adding $T_\theta$ to $T_{minDesign}$, and subtracting $T_\theta$ from $T_{maxDesign}$. This gives a setting temperature range within which the expected movement for a number of setting temperatures is obtained. A table of installation gap widths can be developed to account for varying field temperatures during installation. It is imperative that no design movement for any temperature exceeds the movement capacity of the selected joint.

## 4.0 ANALYSIS AND DISCUSSION OF RESULTS

### 4.1 STEEL GIRDER BRIDGES WITH CONCRETE DECKS

Given a steel girder bridge with concrete deck, for example, with expansion length, L = 76.2m, and skew angle θ = 30º. Then, $T_{maxDesign}$ = 48.89 ºC; $T_{minDesign}$ = −6.67 ºC and $\alpha = 1.24 \times 10^{-5}$/ºC

1. **Estimation of design thermal movement:** From equation (4), we obtain $\Delta_T = \alpha L\ (T_{maxDesign} - T_{minDesign})$
   Hence, $\Delta_T = 1.24 \times 10^{-5} \times 76.2\ [48.89-(-6.67)] = 5.25 \times 10^{-2}$ m
2. **Consideration of skew:** From Equation (7); $\Delta_{TS} = \Delta_T \cos\theta$ and θ = 30º
   Hence,
   $\Delta_{TS} = 0.0525 \times \cos 30 = 0.0455$m; or 1.79"
3. **Consideration of Racking:** From Equation (8) racking allowance R is given as; R = 0.20UB

For strip seals the upper boundary UB of movement range is 101.6mm (4"); thus, UB = 0.1016m.

R = 0.2 x 0.1016 = 0.02032m.

Corresponding movement parallel to joint $MVT_{par}$ is given in equation (9) as,

$MVT_{par} = \frac{R}{\sin\theta}$

But R = 0.02032m; θ = 30º, hence, $MVT_{par} = \frac{0.02032}{\sin 30}$ = 0.04064m.

From equation (10) the corresponding temperature change is

$T_\theta = (T_{maxDesign} - T_{minDesign}) \times \frac{MVTpar}{\Delta T}$

$T_\theta = [48.89-(-6.67)] \times \frac{0.04064}{0.0525} = 43$ ºC

Minimum installation temperature = 48.89ºC– 43ºC = 5.89 ºC. Maximum installation temperature = –6.67 ºC + 43ºC =36.33 ºC. Hence temperature range is between 5.89 ºC and 36.33 ºC.

Racking requires limiting the installation temperature to between 5.89 ºC and 36.33 ºC.

Installation gap widths should be determined for varying field temperatures between or within this range, say 5.89 ºC, 12.78 ºC, 21.11ºC, 29.94 ºC, and 36.33 ºC.

### 4.1.1 Installation Gap Widths at Varying Design Temperatures $T_{Design}$.

L = 76.2m; Skew angle θ = 30º

Movement/degree change in temperature = $\frac{\Delta T}{(TmaxDesign - TminDesign)}$

Movement/degree change in temperature = $\frac{0.0525}{55.56}$ = $9.45 \times 10^{-4}$ m/ ºC

The AASHTO LRFD (2010) specifies a minimum gap of 25.4mm (1")

For this design a minimum gap of 38.1mm (1.5") shall be assumed to be normal to the joint at 48.89 ºC.

Joint opening normal to joint at $T_{Design}$ = 5.89 ºC

= 0.0381(assumed min gap) + ($9.45 \times 10^{-4}$) (48.89 – 5.89)(cos30) = 0.07329m

Joint opening at $T_{Design}$ = 12.78 ºC

= 0.0381+ ($9.45 \times 10^{-4}$)(48.89 – 12.78)(cos30) = 0.06732m.

Joint opening at $T_{Design}$ = 21.11ºC

= 0.0381+ ($9.45 \times 10^{-4}$)(48.89 – 21.11)(cos30) = 0.06083m

Joint opening at $T_{Design}$ = 29.94 ºC

= 0.0381+ ($9.45 \times 10^{-4}$)(48.89 – 29.94)(cos30) = 0.05361m

Joint opening at $T_{Design}$ = 36.33 ºC

= 0.0381+ ($9.45 \times 10^{-4}$) (48.89 – 36.33)(cos30) = 0.04838m

## 4.2 EXPANSION JOINT DESIGN FOR STEEL FLOORS

### 4.2.1 Steel Floors

During the early days of iron and steel framed construction, floors were constructed with comparatively closely spaced iron or steel beams between main beams giving support to shallow brick arches built between them on which concrete was spread to provide a level floor (Stephen and Christopher, 2006).

The advent of reinforced concrete beams have to a large extent replaced the use of steel floors (Stephen and Christopher, 2006). If a steel floor of relatively long span is to be utilized in a construction, there is need to provide expansion joint to the floor.

### 4.2.2 Design of Expansion Joint in Steel Floors.

Given a steel floor with expansion length, L = 36.0m and considering the following parameters, for example:

Skew angle θ = 20º; $T_{maxDesign}$ = 48.89 ºC; $T_{minDesign}$ = – 6.67 ºC and α = 1.24 x $10^{-5}$/ ºC. The solution for the provision of expansion joint can be assessed as shown below.

1. **Estimation of design thermal movement:** From equation (4)
$\Delta_T = \alpha L\,(T_{maxDesign} - T_{minDesign})$
Hence,
$\Delta_T = 1.24 \times 10^{-5} \times 36.0\,[48.89-(-6.67)] = 0.0248$m
2. **Consideration of Skew:** From equation (7)
$\Delta_{TS} = \Delta_T \cos\theta$ ; θ = 20º
Hence,
$\Delta_{TS} = 0.0248 \times \cos 20 = 0.0233$m or 0.92"
The movement anticipated is within the range of pourable seals.
3. **Consideration of Racking:** From Equation (8) racking allowance R is given as;
R = 0.20UB
For pourable seals the Upper Boundary (UB) of movement range is 25.4mm (1")
UB = 0.0254m
R = 0.2 x 0.0254 = 0.00508m
From equation (9) the corresponding movement parallel to joint $MVT_{par}$ is given as,
$MVT_{par} = \frac{R}{\sin\theta}$
When R = 0.00508m and θ = 20º
Hence, $MVT_{par} = \frac{0.00508}{\sin 20} = 0.01485$m
From equation (10) the corresponding temperature range is
$T_\theta = (T_{maxDesign} - T_{minDesign}) \times \frac{MVTpar}{\Delta T}$
$T_\theta = [48.89-(-6.67)] \times \frac{0.01485}{0.0248} = 33$ºC
Minimum installation temperature = 48.89º– 33º = 15.89 ºC
Maximum installation temperature = –6.67 º + 33º =26.33 ºC
Racking requires limiting the installation temperature to between 15.89 ºC and 26.33 ºC.
Installation gap widths should be determined for varying field temperatures within this range. The expansion gap should be determined for a number of temperatures within this range.
The expansion gaps for design temperatures T = 15.89 ºC, 18.33 ºC, 21.11ºC, 23.89 ºC, and 26.33 ºC.

### 4.2.3 Installation Gap Widths at Varying Design Temperatures $T_{Design}$.

L = 36.0m
Skew angle θ = 20º
Movement/degree change in temperature = $\frac{\Delta T}{(TmaxDesign - TminDesign)}$
Movement/degree change in temperature = $\frac{0.0248}{55.56}$ = 4.46 x $10^{-4}$ m/ ºC

Assuming a minimum gap of 25.4mm (1") to be normal to the joint at 48.89 ºC.

Joint opening normal to joint at $T_{Design}$ = 15.89 ºC
= 0.0254(assumed min gap) + (4.46 x $10^{-4}$) (48.89 – 15.89)(cos20) = 0.03923m

Joint opening at $T_{Design}$ = 18.33 ºC
= 0.0254+ (4.46 x $10^{-4}$)(48.89 – 18.33)(cos20) = 0.03821m.

Joint opening at $T_{Design}$ = 21.11ºC
= 0.0254+ (4.46 x $10^{-4}$)(48.89 – 21.11)(cos20) = 0.03704m

Joint opening at $T_{Design}$ = 23.89 ºC
= 0.0254 + (4.46 x $10^{-4}$)(48.89 – 23.89)(cos20) = 0.03588m

Joint opening at $T_{Design}$ = 26.33 ºC
= 0.0254+ (4.46 x $10^{-4}$)(48.89 – 26.33)(cos20) = 0.03485m.

## 4.3 EXPANSION JOINTS FAILURE

Expansion joints when properly designed and installed will extend the life of the structure to which it is installed. For example when bridge expansion joints are well designed and installed, they extend the useful life of the bridge, however, their life span is much shorter than that of the bridge and they deteriorate with traffic. The life span of an expansion joint is dependent mainly on the operating conditions and the temperature range of the region. The thermal load which is temperature that causes an effect on a structure is of importance, knowledge of the thermal load which the expansion joint will be subjected to, and that which the expansion joints can carry will aid designers in determining the probability of failure of the expansion joint. The temperature range $T_R$ which is the difference between the maximum and minimum installation temperatures is given in Equation (10). This can be used to determine the maximum installation temperature consistent with the thermal capacity and the life span of the expansion joint. Once this is known, a temperature range without which expansion joints should not be installed is known. But the variation of temperature in a building and the shape, size and sometimes the use are stochastic in nature. Thus it is necessary not to rely on the deterministic or empirical methods in specifying expansion joints but rather on a more rational and probabilistic method. Therefore, the probability of failure of an expansion joint may be used as a measure of the effectiveness of expansion joints. If G(x) is a limit state probability function derived from the probabilistic reliability analysis theory, which basically represents the probability of a device performing its purpose adequately for an intended period of time under operating conditions encountered (Melchers, 1987), then, the G(x) function is given in the equation below;

$$G(x) = R - S \quad (11)$$

where, R is a function of material property i.e. the resisting capacity of the material and, S refers to applied loads densities and dimensions. The G(x) function is a performance function which depicts the safety margin of the system, and is usually expressed in terms of basic random variables, $\bar{x}$, which affects the performance of the structure; and $\overline{X}$ = ($X_1$, $X_2$, $X_3$, ......, $X_n$). Thus, G(x) < 0 depicts failure; G(x) = 0 depicts attainment of limit state, and G(x) > 0 depicts safety. It follows therefore that the probability of failure is given as: P [G(x) ≤ 0]. Hence, probability of failure, $P_f$ = P [(R - S) ≤ 0]; where, R = resistance of the device; and S = load applied, in this case thermal load.

### 4.3.1 Reliability Index

The reliability index is a commonly used probabilistic measure of safety in addition to the probability of failure (Melchers, 1987). The First Order Reliability Method [FORM] is a very reliable tool for assessing the reliability and hence the effectiveness of structural elements. With FORM the reliability index can be obtained. It is assumed in FORM that G(x) can be linearized so that the tangent plane on its surface can be expressed by first order Taylor series expansion (Gollwitzer et al, 1988).

$$G(x) = G(X_1, X_2, X_3 \ldots X_n) + \sum_{i=0}^{n} \left(\frac{\partial Z}{\partial x}\right)_{xi=xi^*} (x_i - x_i^*) = 0$$

where G(x) = linearized function, G is linearized in $(X_1, X_2, ..X_n)$

n = number of stochastic variable in the reliability function.

$\left(\frac{\delta z}{\delta x}\right) x_i = x_i^*$ = partial derivatives of G with respect to $x_i$, evaluated in $x_i = x_i^*$.

The mean value and the standard deviation of G(x) are:

$$\mu_{G(x)} = G(X^*_1, X^*_2, \ldots X^*_n) + \sum_{i=0}^{n} \left(\frac{\partial Z}{\partial x}\right)_{xi=xi} (\mu_{xi} - xi^*). \quad (12)$$

$$\sigma_{G(x)} = \sqrt{\sum_{i=0}^{n} \left(\frac{\partial Z}{\partial x}\right)^2_{xi=xi^*} \sigma_{xi}^2} \quad (13)$$

By substituting mean value $X_i^* = \mu_{xi} \ldots \ldots . X_{xn} = \mu_{xn}$ the mean value of the probability of failure $P_f$ is obtained and a better approximation can be achieved by linearization of the reliability function in the design point if the boundary is non-linear. The design point is only defined if the variables are normally distributed (or are transformed to normally distributed variables). The design point is defined as the point on the failure boundary in which the joint (normal) probability density is maximum. The design point is given by:

$$X_i^* = \mu_{xi} - \alpha_i \beta \sigma_{xi} \quad (14)$$

where $\mu_{xi}$ is the mean value of the basic variable; $\sigma_{xi}$ is the standard deviation of the basic random variables.

The mean value of the basic random variables can be used as the initial value of the design point. i.e.

$$\mu_x = X_i^*$$

$$\alpha_i = \frac{\sigma(xi)}{\sigma(Gxi)} \cdot \frac{\delta G}{\delta x} \quad (15)$$

$\alpha_i$ = factor of influence of variable i.

$$\beta = \frac{\mu(Gx)}{\sigma(Gx)} \quad (16)$$

Unless G is a linear function the design point cannot be determined directly. An alternative procedure has to be applied. Assume the variables to be independent and normally distributed. Then the following steps can be used; (i) assign value $X_i = X_i^*$ for all i (mainly $X_i^* = \mu_{xi} \ldots X_n^* = \mu_{xn}$ is chosen); (ii) calculate $\mu_{(Gx)}$ and $\sigma_{(Gx)}$; (iii) determine β; (iv) repeat the steps (i) to (ii) several times until the process has converged to sufficiently accurate (final) value; (v) check the $G(X_1^*, X_2^*, \ldots . X_n^*) = 0$; (vi) approximate P{G < 0} by {G(x) < 0) = φ (-β).

By this method satisfactory results are obtained provided the failure boundary is not too sharply curved in the neighborhood of the design point. FORM also provides a means for calculating the partial safety factor. It uses a combination of analytical and approximate methods, and comprises of different stages. All variables are first transformed into equivalent normal space with zero mean and a unit variance, the original limit state surface is then mapped onto the new limit state surface. The shortest distance between the origin and the limit state surface, termed the reliability index, β, is evaluated; this is known as the design point, or point of maximum likelihood, and gives the most likely combination of basic variables to cause failure. The probability associated with this point is finally calculated. FORM can easily be extended to non-linear limit states and has a reasonable balance with ease of use and accuracy (Gollwitzer, et al, 1988; Rackwitz and Fiessler, 1978).

The First Order Reliability Method (FORM) is one of the most common basic techniques and is applicable to all probabilistic problems. It does not depend on the number of simulations to be carried out and this makes it the preferred method (Melchers, 1987; Ditlevsen and Madsen, 2005).

### 4.3.2 Steel Girder Bridge with Concrete Deck

The American design codes (AISC, 2005; AASHTO LRFD, 2004; 2010) specify a minimum expansion joint width of 25.4 mm (1 inch) for all structures requiring expansion joints. For strip seals the maximum allowable expansion is 101.6mm (4inches). Hence in applying the reliability theory we take R = 101.6mm. Expansion that will occur due to change in temperature is given as in Equation (1)

$\Delta L = \alpha L \Delta_\theta$

where, ΔL = change in length due to temperature; L = expansion length (tributary length); $\Delta_\theta$ = temperature change. Thus,

$S = \alpha L \Delta_\theta$

Recall, G(x) = R – S, then, the limit state function for the expansion joint is

$G(x) = (101.6 - \alpha L \Delta_\theta)$

## 4.4 RESULTS AND DISCUSSION

The results are indicated in Figure 1 for the various tributary spans or lengths considered.

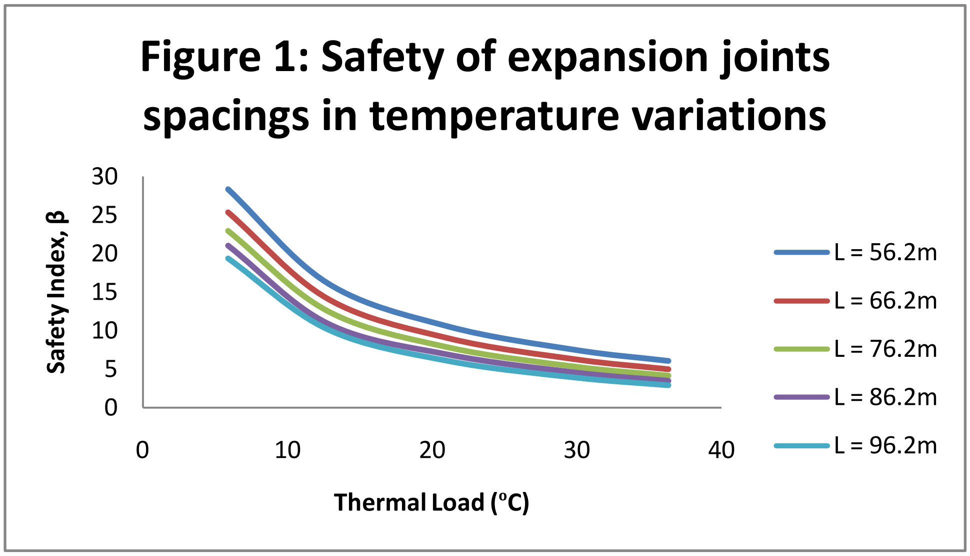


Figure 1: Safety of expansion joints spacing in temperature variations.

It can be seen that the curves slope from the maximum values to the minimum values, hence it is clear that higher values of temperature corresponds to lower values of safety index, which depicts less safety of the expansion joint, and hence less effective. It can also be seen that with shorter tributary length (expansion length), higher values of safety index (β) is obtained, which shows that expansion joints are safer with shorter expansion lengths and modules. Therefore it is emphasized that expansion joints are more effective with shorter expansion lengths or modules and lower temperatures. Furthermore, the effectiveness of an expansion joint is inversely proportional to the combined formulation of the expansion length and corresponding temperatures.

## 5.0 CONCLUSION AND RECOMMENDATIONS

The primary aim of this presentation is to assess the effectiveness of expansion joints. From the design, analysis and results obtained it is observed that expansion joints are less effective with longer expansion lengths and higher temperatures. To a large extent, the number of expansion joints to be used for a particular length or structural module is dependent on the designer's experience and existing conditions.

This work emphasizes the provision of simple means of allowing room for natural expansion and contraction through expansion joints, which in turn will reduce the internal pressure due to secondary effects on the structural system.

In summary, properly applied, located, and detailed expansion joints are important criteria for safety of structures; therefore designers must accord them the attention they deserve.

The values of structural safety indices were obtained using recommendation from AASHTO LRFD (2010) design specifications, that the minimum expansion joint gap should not be less than 25.4mm. This presentation upholds this recommendation.

The EC3 (2004), BS5950 (2000) and the AISC (2005) should be reviewed to include procedures for design of expansion joints, so that less decisions with regards to the considerations herein are dependent on the designers initiative or rule of thumb.

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