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Study of Temperature Load on Structure's

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Abstract: *Thermal load is defined as the high temperature that causes the effect on any structure, such as outdoor air temperature, solar radiation, underground temperature, indoor air temperature and the heat source equipment inside the building or material storage tanks with variation in temperature. The basic thermal load is the 100-year-return period of transform in outdoor air temperature, solar radiation, underground temperature or equivalent value.*

Performance of any structure as soon as ex- posed to fire depends on the material properties and in-barriers to withstand or to confine fire, Concrete structures be capable to have enormous performance for the duration of fire event if the concrete has lower thermal conductivity which leads to slower increase of the concrete temperature. For steel structures, strength, ductility, consistency of the steel material, shape of the structure and the applied load are significant factors which should be observed for fire resistance calculation. The critical/essential temperature depends on the load ratio and steel composition.

Keywords*: Thermal Load, Thermal Expansion, Thermal bowing, Fire, Steel Concrete, Solar, temperature*

1. Introduction

Thermal load is defined as the high temperature that causes the effect on any structure, such as outdoor air temperature, solar radiation, underground temperature, indoor air temperature and the heat source equipment inside the building or material storage tanks with variation in temperature. The change of the temperature in the structural and non-structural member causes thermal stress and is defined as the effect of thermal load. Sustainability of structures is a main concern in the construction industry. Exposure to snow or fire or elevated temperature is an extreme condition that leads to change in material properties, consequently, change in overall behaviour is expected. If member expansion is restrained then thermal stresses are developed. High temperature causes loss of strength and stiffness which weaken the structure. Response of member to combined thermal and mechanical loading for different types of restrains is studied which is helpful in understanding the behaviour of mechanical structure.

Largely situations in real structures under temperature variation have a complex mix of mechanical strains due to applied loading and mechanical strains due to restrained thermal expansion developed. All methodical analytical expressions developed using concepts in fundamental structural mechanics. The mainly fundamental relationship that governs the behaviour of structures while subjected to thermal effects is governed by relationship

$$\epsilon_{Total} = \epsilon_{Thermal} + \epsilon_{Mechanical} \quad \ldots\ldots\ldots\ldots(1)$$

Sum of strain in structural member is the summing up of thermal strain and mechanical strain. The stress in structure depends only on mechanical strain. Thermal stress will be developed only when thermal strains are fully restrained. Mechanical stress will depend upon the cross sectional area of the member.

The initial temperature is defined as the temperature which causes no thermal effect on a building. The temperature variation Δ T has two parts, mean cross-section temperature Δ Td and the temperature gradient in the cross-section Δ Tg / t.

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2. Consideration of thermal load

Thermal loads must be considered for the following construction types: building constructed in an area where there is a considerable transformation in outdoor air temperature, building with huge length, building with huge space inside, building with straight influence of solar emission like a building with glass roof, building or structure with heat resource such as a chimney, silo containing hot or warm material, heat storage tank, refrigerated warehouse and electric power plant. When the building is divided into smaller parts with expansion joints to diminish the movement in each part, or the temperature change in the structural member is reduced by thermal filling, thermal load may not be considered.

3. Thermal Load

The basic thermal load is the 100-year-return period of transform in outdoor air temperature, solar radiation, underground temperature or equivalent value.

The fundamental thermal load of outdoor air temperature is based on the 100-year-return period value of the twelve-monthly highest and lowest temperature. The temperature in a member must be designed using the outdoor air temperature and/or solar radiation, in consideration of the category of the structure, reinforced concrete structure or steel structure, solar radiation incorporation factor, thermal inertia, heat transfer coefficient, and the annual and daily variations of temperature and solar effect.

It is suggested that the temperature in the member be designed using time-history analysis considering the change of outdoor air temperature and solar radiation. It is also feasible to calculate the temperature in member with steady state of highest or lowest temperature, ignoring the everyday change, but the consequence of the calculation may be too conservative when the member has large thermal inertia, like a reinforced concrete member.

3.1 Outdoor air temperature:

(1) 100-year-reccurence value of uppermost and lowest outdoor air temperature: The 100-year-reccurence value of peak and lowest outdoor air temperature is calculated using fitting of acute value distribution on data obtained from Meteorological Office.

(2) Time history data of outdoor air temperature and solar radiation: The time history statistics based on the 100-year-reccurence value is still not available.

3.2 Solar radiation:

The consequence of solar radiation on a building should be considered using Sol-Air Temperature TSAT

TSAT = T0 + J a/α0 …………………. 2

Where

T0: Outdoor air temperature

J: Solar radiation

a: solar absorptive

α0: total heat transfer coefficient of outer surface

3.3 Underground temperature :

The underground temperatures have to be considered to settle on the thermal effects on basement structures and foundations. A day by day change of temperature reduces to only 0.5 meter below grade. Where it is deeper than 10 meters from the ground surface, it is considered that the temperature do not vary and is equal to the twelve-monthly mean air temperature.

3.4 Indoor temperature:

The interior temperatures have to be determined by evaluating the planned air-conditioning environment. It is as well significant to mull over the indoor temperature for the stipulation when the building's air-conditioning does not function as expected. It is perfect that the indoor temperature once it is not air-conditioned be calculated bearing in mind the thermal insulating properties of the building, but it is also possible to regard as the temperature of the structural members of the building to be the equivalent as the outdoor air temperature.

3.5 Other temperatures:

A number of data from the actual measurement of a variety of building structures are introduced.

4. Thermal Expansion

Heating induces thermal expansion strains (say eT) in the majority portions of the structural materials. These are given by

Є T = αΔ T …………………….. 3

If a consistent temperature rise, ΔT; is applied to a simply supported beam devoid of axial restraint, the effect will simply be an expansion or increase in distance end to end of lαΔT as shown in Figure 1. As a result the total strain (say Є T) is equal to the thermal strain and there is no mechanical strain (say Є M) which means that no stresses develop in the beam.

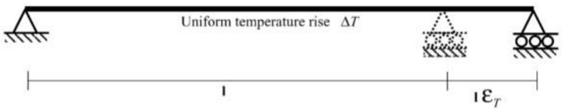

Fig. 1. Uniform heating of a simply supported beam.

4.1 Thermal Expansion Against Rigid Lateral Restraints

Evidently, beams in actual structure do not have the freedom to elongate in the method explained above. As a result, a more rational case to consider, an axially restrained beam subjected to a homogeneous temperature increase, Δ T (as shown in Figure 2). It is apparent to perceive that in this case the totality of strain Є T is zero (i.e. no displacements). This is for the reason that the thermal expansion is annulled out by equal and opposite contraction caused by the restraining force P (i.e. Є T = Є T + Є M = 0 therefore Є T = - Є M). There at present exists a consistent axial stresses in the beam equal to E Є M: The magnitude of the restraining force P is,

P = EA Є M = - EA Є T = - EAαΔ T ………………….. 4

Fig. 2. Axially restrained beam subjected to uniform heating.

If the temperature is allowed to increase for an indefinite period, then there will be two basic responses, depending upon the slenderness of the beam:

4.1.1 If the beam is adequately stocky, after that the axial stress will sooner or later reach the yield stress σy of the material and if the material have an elastic–plastic stress–strain association, then the beam will persist to yield without any additional increase in stress, however it will also store an increasing magnitude of plastic strains. The yield temperature increase ΔTy is,

$\Delta Ty = \sigma / E\alpha$

4.1.2 If the beam is slender after that it will buckle earlier than the material reaches its yield stress. The Euler buckling load Pcr for a beam/column, as in Figure 2 is

$$Pcr = \frac{\pi^2 EI}{l^2}$$

Equating this to the restraining force P; we have,

$$EA\alpha\Delta T = \frac{\pi^2 EI}{l^2}$$

This leads to a critical buckling temperature of,

$$\Delta Tcr = \frac{\pi^2}{\alpha}\left(\frac{r}{l}\right)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

OR

$$\Delta Tcr = \frac{\pi^2}{\alpha\lambda^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

Where 'r' is the radius of gyration and 'λ' is the slenderness ratio (l/r) This expression is applicable for other end-restraint conditions if 'l' is interpreted as the effective length.

In this case, if the temperature is allowed to increase further, after that the totality of restraining force will stay steady (assuming an elastic material and no thermal dilapidation of properties) and the thermal expansion strains will carry on to be accommodated by the outward deflection of the beam d as revealed in Figure 3.

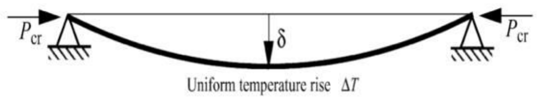

Fig. 3. Buckling of an axially restrained beam subjected to uniform heating.

The above cases characterize the two elementary responses in beams subjected to controlled thermal expansion. Either of the two (yielding or buckling) can occur on its own (based upon the slenderness of the beam) or an extra complex response consisting of a grouping of yielding and buckling may possibly also occur [1].

4.2 Thermal Expansion against Finite Lateral Restraints

In the preceding discussion it was assumed the axial restraints to be flawlessly rigid. This is an upper limit and virtually impossible to accomplish in real structures which offer merely finite restraints. Figure 4 describes such a beam restrained axially by a translational spring of stiffness 'kt'. The compressive axial stress developed by thermal expansion is

$$\sigma = EA\alpha\Delta T$$

$$\sigma = \frac{E\alpha\Delta T}{(1+EA/ktL)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 7$$

and critical buckling temperature is now given by

$$\Delta Tcr = \frac{\pi^2}{\alpha\lambda^2}\left(1+\frac{EA}{ktL}\right) \quad \ldots\ldots\ldots\ldots 8$$

From Eq. (8) it be capable of, be seen that buckling and post-buckling phenomena have to be observable at reasonable fire temperatures in structures with translational restraint stiffness's 'kt' which are relatively comparable by means of the axial stiffness's of the member 'EA/L' Figure 5 shows a plot derived from Eq. (8), where critical buckling temperatures be plotted in opposition to slenderness ratio for different restraint stiffness's. The results undoubtedly demonstrate that the amount of restraint required is not large intended for slender sections to reach buckling temperature. Bearing in mind with the intention of the axial stiffness's of the member 'EA/L' is reduced by heating through the reduction in 'E'; these post- buckling phenomena are very probable to be observed in beams in typical fires.

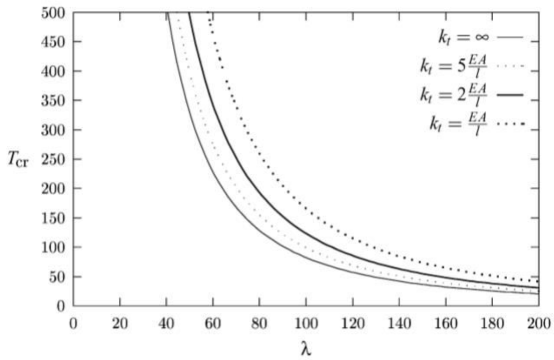

Fig. 5: Buckling temperatures for thermal expansion against finite lateral resistant.

4.3 Thermal bowing

In real fires the temperature distributions are no matter what, but uniform. In a small to moderate size compartment of a regular shape one may perhaps assume that the compartment temperature will be approximately uniform at a given time. The temperature of the structural members in the compartment depends in the lead the material they are made of and other information of geometry, construction and design (such as insulation). Concrete beams and slabs on the ceiling of the compartment can be subjected to very towering temperature gradients due to the very slow rates of heat transfer to concrete. As a result, the surfaces exposed to fire will be at a great deal of higher temperature than the surfaces on the exterior of the compartment. This causes the inner surfaces to increase a great deal more than the outer surfaces inducing bending in the member. This effect is called thermal bowing is one of the main reasons of the deformations of concrete slabs and masonry walls in fire. Another very significant source of thermal bowing in composite beams/slabs is the great difference between the temperatures of the steel joist and the slab. This effect is much more significant in the early stages of the fire when steel retains for the most part of its strength [4].

Relationships are able to be derived for thermal bowing analogous to the one derived earlier for thermal expansion. Figure 6 shows a beam subjected to a consistent temperature gradient all the way through its depth'd' along its whole length 'l'. Assuming the beam is simply supported (as shown in Figure 6), it can derive the subsequent relationships.

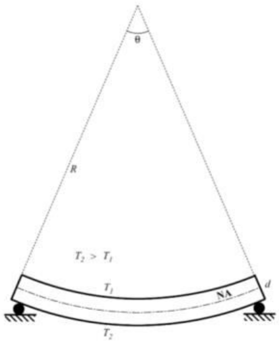

Fig. 6: Simply Supported Beam subjected to a uniform thermal gradient

1. The thermal gradient 'T,y' over the depth is,

$$T,y = \frac{T_2 - T_1}{d}$$

2. A uniform curvature 'f' is induced all along the length as a result of the thermal gradient

$$\emptyset = \alpha T y$$

3. Due to the curvature of the beam, the horizontal distance between the ends of the beam will decrease. If this reduction is interpreted as a contraction strain (not literally) 'ef ' (analogous to the thermal expansion strain Є T; earlier), then the assessment of this strain can be calculated from analysing Figure 6 as:

$$\epsilon\,\emptyset = 1 - \frac{\sin(\frac{l\emptyset}{2})}{\frac{l\emptyset}{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..9$$

Considering laterally restrained beam as depicted in Figure 3, if a uniform thermal gradient 'T,y' (without any average rise in temperature) is applied to this beam (as shown in Figure 7), subsequently the result is a thermally induced tension in the beam and corresponding reactions at the holdup points (opposite to the pure thermal expansion case discussed earlier). This is clearly caused by the restraint to end translation against the contraction strain ($\epsilon\,\emptyset$) induced by the thermal gradient. Figure 8 depicts a fixed ended beam (by adding end rotational restraints to the beam of Figure 7) subjected to a homogeneous temperature gradient throughout its depth.

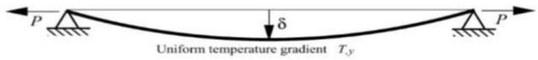

Fig. 7. Laterally restrained beam subjected to a uniform thermal gradient

Fig.8. Fixed Beam subjected to a unform thermal gradient

4.4 Defections

One interesting aspect of structural response to fire is huge deflections that are found in structural members like beams and slabs. Large deflections are normally connected with the loss of strength in structures under ambient conditions. In case of fire, such a simple interpretation can be exceedingly misleading. The main or chief reason for large deflections is that the structural member tries to accommodate the extra length generated by thermal expansion, known that it is not possible for it to expand longitudinally owing to end restraints. Consider a slender beam (very low buckling temperature) subjected to uniform heating alongside rigid lateral restraints (as in Figure 3). Buckling will occur incredibly early (at very low elastic strains), following which any further expansion will make the beam deflect outwards. The resulting deflection at mid-span 'd' can be approximated pretty accurately by

$$\delta = \frac{2l}{\pi}\sqrt{(\varepsilon T + \varepsilon^2 T/2)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots10$$

5. Structural Performance and Design Requirements

Performance of any structure as soon as ex- posed to fire depends on the material properties and in- barriers to withstand or to confine fire. Nevertheless, fire resistance rating is an indicator concerning the expected fire resistance of a structure in half-hour or hourly increments [2].

Thermal expansion, structure end conditions (re- strained or unrestrained), and loss of materials' strength and stiffness have an effect on the overall performance of an explicit structure.

Concrete structures are capable to have enormous performance during fire event if the concrete has lesser thermal conductivity which leads to slower increase of the concrete temperature. Spalling of concrete during high temperature could affect the mechanical properties of concrete due to the rise of vapour pressure. This pressure leads to internal cracks and stress which exceeds the tensile strength of the concrete. Hertz and Sorensen established that concrete does not spall if the moisture content was kept less than 3% per weight, however, if the moisture content is more than 3%, spalling /explosive spalling may possibly be avoided by means of cementations materials such as silica fume or fiber concrete.

For steel structures, strength, ductility, consistency of the steel material, shape of the structure and the applied load are significant factors which should be observed for fire resistance calculation. The critical/essential temperature depends on the weight ratio and steel composition. The weight ratio value is the ratio of the applied design load to that would generate a stress equal to yield stress at room temperature [1,2]. It is essential to apply padding material such as magnesia, vermiculite, sprayed mineral and ablative coatings to shield the steel structure from high temperature [2].

In composite structures, stresses and displacements caused by thermal expansion direct the structural behavior in fire, until just earlier than the failure reduction in material strength and stiffness control the behavior again.

6. Conclusion

Thermal loads must be considered for the following construction types: building constructed in an area where there is a considerable transformation in outdoor air temperature, building with huge length, building with huge space inside, building with straight influence of solar emission like a building with glass roof, building or structure with heat resource such as a chimney, silo containing hot or warm material, heat storage tank, refrigerated warehouse and electric power plant.

For steel structures, strength, ductility, consistency of the steel material, shape of the structure and the applied load are significant factors which should be observed for fire resistance calculation. The critical/essential temperature depends on the load proportion and steel composition.

Concrete's outstanding fire resistance has been proven by numerous tests performed for more than 60 years. Various building codes have developed prescriptive and systematic analytical methods based on the fire tests on concrete components of structures. These methods present architects and engineer a relatively easy way to select member proportions and reinforcement necessities for all, but the very unusual structures.[1,2] For the very unusual structures, alternate methods are available to satisfactorily model or to test the complex behavior of reinforced concrete components subject to fire.

7. References

[1.] A.S.Usmani and J.M. Rotter, Fundamental Principles Of Structural Behaviour Under Thermal Effects, School of Civil and Environmental Engineering, University of Edinburgh

[2.] Sherif Yehia, Ghanim Kashwani, Performance of Structures Exposed to Extreme High Temperature—An Overview, Open Journal of Civil Engineering Vol. 3 No. 3 (2013) , Article ID: 36202 , 8 pages DOI:10.4236/ojce.2013.33018

[3.] Darshan1, Sanjith J2, Ranjith A3, Chethan G4, A Critical Review On Fire Resistance Structures, International Journal Of Current Engineering And Scientific Research (IJCESR), ISSN (PRINT): 2393-8374, (ONLINE): 2394-0697, VOLUME-3, ISSUE-3, 2016.

[4.] 1Manish Nigam, 2Awadhesh Kumar Singh ,3Abhishek Dixit, Fire Load Calculation on Hospital Buildings in India, International Journal of Engineering Development and Research (www.ijedr.org), 2016 IJEDR | Volume 4, Issue 2 | ISSN: 2321-9939.

[5.] Konstantinos Miamis, A Study Of The Effects Of High Temperature On Structural Steel Framing, December 2007 ,Purdue University ,West Lafayette, Indiana.

[6.] A.S. Usmani*, J.M. Rotter, S. Lamont, A.M. Sanad, M. Gillie, Fundamental Principles Of Structural Behavior Under Thermal Effects, Fire Safety Journal 36 (2001) 721–744

[7.] Hongbo Liu 1 , Zhihua Chen 1,2,* and Ting Zhou 1, Investigation On Temperature Distribution And Thermal Behavior Of Large Span Steel Structures Considering Solar Radiation, Advanced Steel Construction Vol. 9, No. 1, pp. 41-58 (2013).

[8.] H. Saito, H. Uesugi, And M. Yamaguchi, A. Kodaira, Thermal Stress and Deformation of Steel Structures of High Rise Buildings in Fire, Fire Safety Science-Proceedings of The Second International Symposium, pp. 719-728.