Temperature effects during construction No. 7.02

Scope

This Guidance Note provides some general information about the effects of temperature variation during bridge construction. Temperature variation causes the bridge to change length and, to some extent, to change shape (in profile and plan). This may require action to allow for the changes and for the differences between actuality and design assumptions; some general advice is given.

Design

The actions due to temperature change in a bridge are given by EN 1991-1-5 in relation to a uniform initial temperate T_0. Design values of displacements at sliding bearings and at expansion joints are determined according to the variation from this initial temperature. The designer should, according to EN 1993-2, A.4.2.1, record this reference temperature on the drawings and give the required locations of the fixed and sliding bearings at this temperature. This information will allow the constructor to set the bearings appropriately during construction.

However, to set the bearings during construction, the constructor needs to know the effective uniform temperature of the bridge at the time. The temperature can be measured or can be estimated (as long as it is within 10°C) - for the latter case an allowance for uncertainty must be made in determining the design ranges (and the choice of estimation, rather than measurement, must have been anticipated in design).

The question thus arises as to what measures need to be taken during construction, at the key stages when dimensions are fixed, to establish the actual temperature of the bridge. When the temperature is not uniform, questions arise not only over length but over other dimensions (transverse, rotational, etc) when settings have to be fixed.

Considerations

The principal considerations in establishing effective temperature are:

- Solar radiation. Of the effects causing changes in effective temperature, **the total solar radiation is the most powerful and rapid. The effect is so strong that it does occur even through ordinary cloud cover**.
- The effects are quicker to be felt and quicker to dissipate in steel elements than in concrete. This effect is exaggerated if the steel is painted a dark colour.
- Clearly, the response of faces exposed to solar radiation is related to the orientation of that face to the incident energy. This means that low early or late sun or even low midday sun in the winter, will have a significant effect on the vertical faces and high summer or midday sun will have an effect on the horizontal surfaces of a structure.
- The effects of solar radiation are likely to be experienced disproportionately by different parts of the structure, leading to differential temperatures in the elements, with resulting distortion.
- The nature of the distortion is extremely difficult to predict. Hot sun shining on the deck of a deep girder bridge will cause the whole structure to expand and the girder to tend to hog between supports, but the effect will be unequal on a long main span compared to a short side span. This may actually cause the bearings to move in entirely the opposite direction to that expected in other conditions.
- Notwithstanding the above, open steelwork, such as a truss, responds very quickly (within an hour) to all changes in ambient temperature, whether exposed to sunlight or not. Closed box sections tend to have a significant lag in response (3 to 5 hours).

Observations

A number of observations made over the years can be useful in determining whether there is likely to be a difficulty with a particular structure:

- On very long structures, there can be significantly different effects at different cross sections, especially if over different topography.
- Narrow decks are more susceptible to lateral distortion than wide decks.

- Deep girders behave more unpredictably than shallow girders.
- Box girders are more problematic than plate girders, and they can bend considerably in both the vertical and horizontal directions.
- Wide concrete decks which protect the steelwork from direct sunlight reduce the major effects.
- Structures with significant heat-sinks respond more slowly than plain steel skeletons. Concrete decks have a significant damping effect and the air inside box girders tends to slow and reduce the effects.
- Thin plated structures react more quickly to radiant heat and reach higher temperatures.
- A concrete deck surfaced with 'black-top' will react more than an unfinished concrete surface.
- An unsurfaced steel deck will respond more quickly to radiant heat and can reach higher temperatures than even a black-top surfaced concrete deck
- As the effects vary during the day, it is particularly important to be aware of them during the making of the site joints. Bolted joints could be locked up with unintended distortion built into the joint; incomplete welded joints could become over stressed and fail during the night following a hot, sunny day.
- All these effects are likely to be more troublesome with partly completed structures, i.e. during the erection process.
- Towers and piers react to diurnal variations in the position of the sun.

Assessing effective temperature for setting out purposes

It can be difficult to determine the effective uniform temperature in practice because the two major influences (direct solar radiation and the subsequent dissipation of the stored thermal energy from the structure by radiation, conduction and convection) are transient and variable. However, this gives a clue as to how to deal with the problem, i.e. by reducing the effect of these influences to a minimum whenever one is faced with the need to know the effective temperature of the bridge or parts thereof.

The most reliable information is acquired by avoiding the periods of day when solar radiation is present and also avoiding circumstances where the rate of change of temperature is significant.

Ideally, all setting out activities that are critically dependent on establishing effective temperature should be carried out at about three o'clock in the morning after three days of heavy cloud, with dry, still weather when there has been little or no significant change in the ambient temperature! In those circumstances the temperature of the (whole) structure will be as close to the ideal measured ambient air temperature as it will ever be. As the circumstances of this counsel of perfection are seldom achieved, and even less likely to be possible within the programme constraints, the advice is to avoid the contrary situation, i.e. do not attempt to set any critical components in bright sunlight, on a windy day, or after a cold night.

However, having made the above comments about how bridges respond and when reliable measurements can be made, it is pertinent to emphasise strongly that **it will not be necessary to undertake an accurate exercise to establish the effective temperature of most of the bridges that come within the range of spans covered by this series of Guidance Notes, i.e. up to about 50 m.**

Only for long structures, including multi-span viaducts, and decks of more complicated structures, such as lift bridges and swing bridges, will it be necessary to undertake special measures to establish the effective bridge temperature during the setting of bearings, expansion joints and pivoting/ locking devices.

Release of bearing transit cleats

In most bridges (those less than 100 m long) the thermal expansion/contraction of the steelwork on erection (i.e. the difference between nominal and actual at the time of erection) is very small and can be taken up in the clearance between the lower fixings and the concrete. Subsequent movements will also be small and will often not require the release of the transit cleats until the bearings are grouted. This relies on distortion of the transit cleats or on the bottom plate of the bearing sliding on the packs.

On longer bridges, however, the thermal expansion/contraction on erection is often larger than the clearance in the pockets, so the transit cleats have to be released and the top and bottom plates of the bearing offset from each other during erection in order to make the fixings. This has to be done carefully and be closely supervised to avoid disrupting any PTFE pads and seals in the bearing. Care also has to be taken to let the steelwork expand and contract in a controlled manner after erection and before grouting the bearings to avoid breaking the transit cleats or disrupting the packs under the bearing. It is good practice therefore on longer bridges to release the transit cleats once the steelwork has been landed.

Recommendations

In all cases, by far the best advice is to observe what happens at supports as often as possible. A pattern of behaviour related to conditions preceding and during observations, is a much better guide than attempting to calculate behaviour in relation to a limited number of temperature measurements.

Correlating behaviour with predictions is much more reliable in stable and overcast conditions than in sunny or changing conditions, so make sure that there are sufficient observations under stable conditions.

For most composite bridges (up to around 100 m length), very few temperature measurements need to be made in order to establish a sufficiently accurate evaluation of the position of the steelwork at 'datum' temperature (and thus how the bearings should be set). Measurements need only be made of ambient shade air temperature in one or two locations.

For longer bridges, more accurate evaluation will probably be needed, but, fortunately, the construction period will probably be longer and this will offer more opportunity for observation. It may be helpful to monitor steel temperatures at the same time as ambient temperatures. In such cases temperatures at top and bottom flanges should be measured.

References

TRRL reports:

LR 561, The calculation of the distribution of temperature in bridges, Emerson, M., 1973.

LR 696, Bridge temperatures estimated from the shade temperature, Emerson, M., 1976.

LR 702, Bridge temperatures calculated by a computer program, Emerson, M., 1976.

LR 744, Extreme values of bridge temperatures for design purposes, Emerson, M., 1976.

(All published by Transport and Road Research Laboratory, Crowthorne.)

EN 1991-1-5:2003 Eurocode 1. Actions on structures. General actions - thermal actions

EN 1993-2:2006 Eurocode 3 Design of steel structures. Steel bridges.