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Thermal Cycling of Bridge Bearings

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A supplier of polychloroprene has suggested that bridge bearings should not crystallise because there is always sufficient thermal cycling to induce bridge movement and stop the formation of crystals in the elastomer. It is argued that thermal cycling is unlikely to be sufficient at mid to high latitudes in winter to inhibit crystallisation, that is at the time when the risk of crystallisation is greatest.

One of the suppliers of polychloroprene has proposed that elastomeric bridge bearings are unlikely to crystallise as movement of the bridge will inhibit the formation of crystals within the rubber[1,2]. This appears to be a reasonable proposition as the bearings are installed to accommodate thermal expansion and contraction of bridges. Nevertheless, such movement may be strongly seasonal in nature, especially at mid to high latitudes and may be the subject of local micro-climatic factors.

The amount of movement is dependent on the material from which the bridge is built: steel is more responsive to temperature than concrete[3]. Whereas the temperature of concrete bridges tends to approximate to the ambient shade temperatures, those of steel bridges may fall to 3°C–4°C below the minimum ambient shade temperature in Britain (and presumably even lower elsewhere) and rise to 1.5 times the ambient shade temperature expressed in degrees Centigrade (and presumably higher elsewhere)[4]. The temperature of the bearing is likely to reflect that of the underside of the bridge, and any changes will be less than that on the surface.

Over twenty years ago, maps were prepared[5], which attempted to define areas where natural rubber should have an advantage over polychloroprene in terms of crystallisation resistance. These maps (*Figure 1*) depict areas which are likely to experience prolonged periods (*i.e.* one month or longer) of temperatures below freezing (0°C). Such data were, in the main, not directly available, and the criterion selected was a monthly mean of –5°C or less (the monthly mean is the average of the daily mean maximum and minimum temperatures). The criterion was selected with the assistance of the British Meteorological Office and was tested against daily data for Copenhagen in February 1947, when the mean for the month was –6.3°C and the maximum reached –1.3°C.

Subsequently, data have been compiled, which appear to confirm that the criterion selected was correct. Data have been plotted, which show that a significant area in Nebraska[6] is liable to experience periods of one month in which the temperature does not rise above 0°C. The maps are probably conservative in that both Europe and North America have experienced winters with exceptionally low temperatures during the last thirty years. For instance, in 1963 (which was an exceptionally severe winter in parts of Europe), the monthly mean[7] in Strasbourg was –5.4°C in January and –5°C in February. In De Bilt in the Netherlands, the monthly mean was –5.2°C in January, and in Uccle (Belgium), the January mean was –4.5°C.

Ultra-low temperatures are of considerable military significance and these have been plotted by the United States Air Force[8]. These include maps which show the probability of temperatures below –40°C. The data generally

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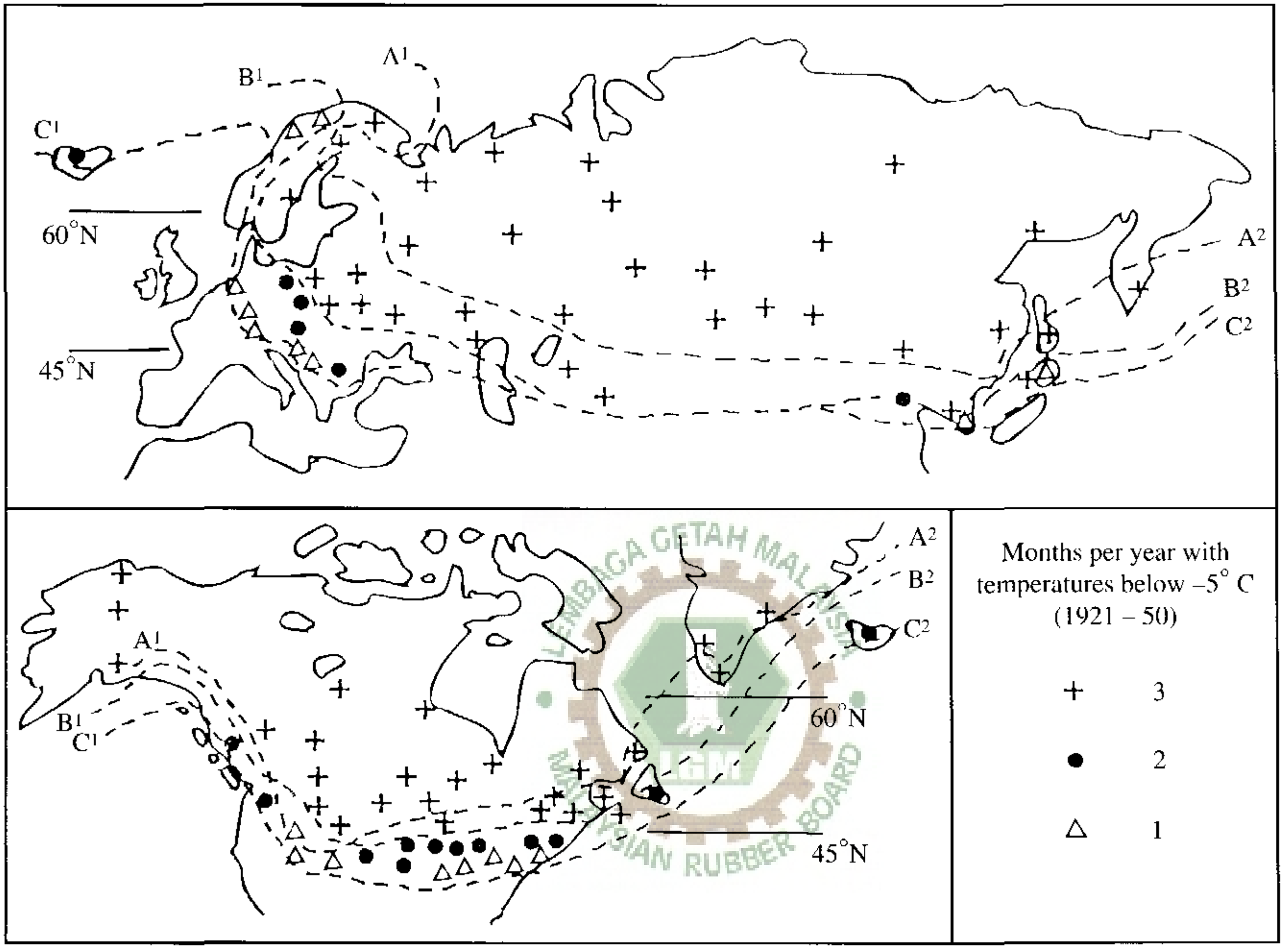

Figure 1. Map showing areas which are likely to experience prolonged periods of temperatures below freezing.

correspond with the maps described above[5]. Therefore, it is believed that these maps form a valid basis for predicting areas where there is a risk of elastomer crystallisation during prolonged periods at low temperatures.

Nevertheless, it still needs to be shown that winter tends to be a season in which temperature changes are less than in summer, and that this is usually markedly so in areas which are liable to experience low temperatures. Studies of the thermal behaviour of actual bridges in the United Kingdom[9] indicate that there is a very marked difference in the thermal behaviour of bridges between summer and winter (*Figures 2* and *3*). Ambient temperature changes are of three types:

- Diurnal or daily
- Seasonal
- Variation on a day-to-day basis, within seasons.

In general, the annual range of temperature is greatest at high latitudes and lowest at the Equator. At, or near the Equator, there is virtually no variation in temperature on a seasonal basis, even at high altitudes, such as the Cameron Highlands in Malaysia. The greatest diurnal ranges occur in mid latitudes (the classic desert regions). Day-to-day changes are greatest in mid to high latitudes and may be caused by relatively local factors, such as the warm and cold winds associated with areas relatively near to high mountains. The mistral brings the cold from the Alps to the Mediterranean. The chinook warms the Prairies with frictionally warmed air from the Rockies.

In mid to high latitudes, the most extreme diurnal variation is experienced in late spring (May) and summer. The basic mechanism for this is solar elevation: at 43°N (Central Wyoming), the solar elevation is only 23° in December compared with 70° in June[10]. At 63° North and South, the sun does not rise in

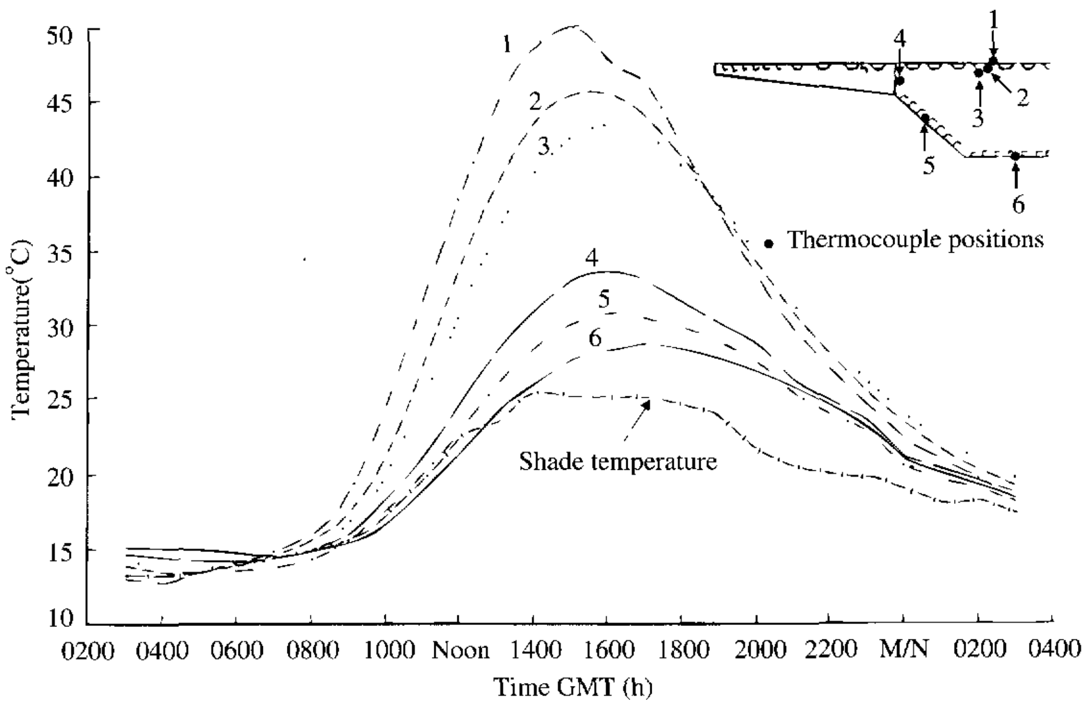

Figure 2. Temperature distribution — steel box (summer).

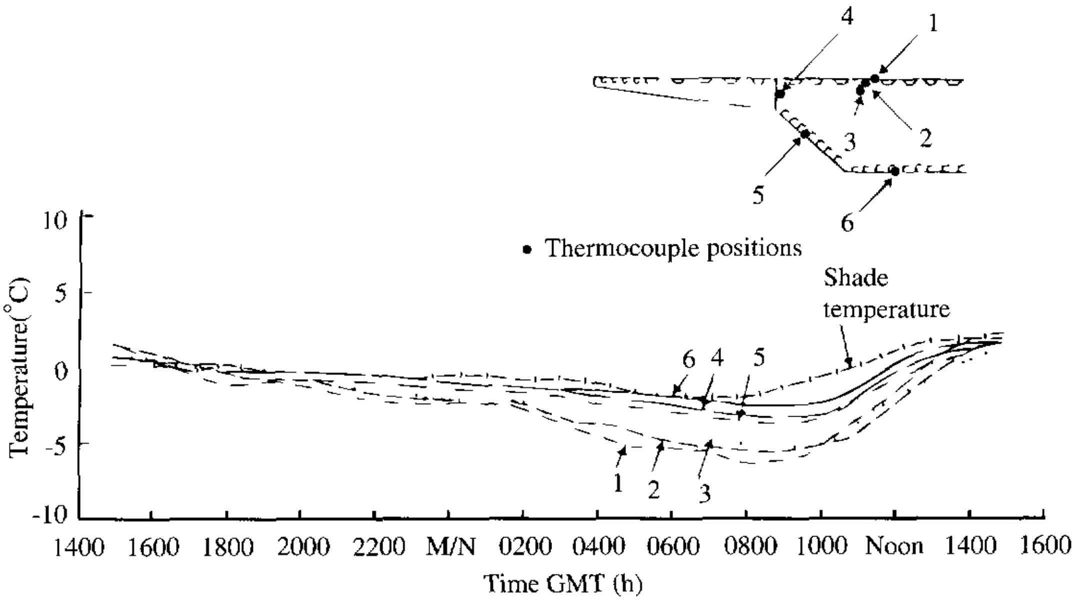

Figure 3. Temperature distribution — steel box (winter).

mid-December or set in mid-summer: in the Arctic, the term 'diurnal' ceases to be meaningful in the depths of winter or during the height of summer. Furthermore, in Northern Europe, cloud cover in winter reduces solar heating still further. For instance, Warsaw has twenty days without sun in the average December. As this is probably partly due to pollution, it may be compared with Strasbourg (48°S) with nineteen sunless days or the more northerly, but cleaner Goteborg (nearly 58°N) with fifteen sunless days, but only 29 h of weak sunshine. This is markedly different from central North America where there are far fewer sunless days even in December: Ottawa and Montreal with thirteen and Edmonton with only seven sunless days.

Table 1 illustrates these characteristics through data extracted from cumulations extending over periods typically of at least thirty years[11,12]. The diurnal ranges are expressed in the form of average daily maxima and minima temperatures for the months concerned at the locations indicated. Normally the difference between winter and summer is quite marked. This would appear to indicate that the opportunity for thermal movement within bridges will be less marked during the time when crystallisation of the elastomer is most probable.

As solar radiation is greatest in intensity in summer, bridge movement will also be greatest at this time. In winter, the diurnal temperature range tends to be around 70% of that in summer, and may be even less at 60°N (*Table 1*). This characteristic applies not only to areas which are cold in winter and hot in summer (the North American Prairies, for instance), but also to locations which are mild in winter (such as Lisbon and Plymouth). The only area which breaks this pattern in North-east Asia (Eastern Siberia and Northern Japan) where the ultra extremes of winter cold are greater than the extremes experienced in summer: Eastern Siberia is the coldest part of the planet outside the Antarctic.

Another factor which may need to be considered is that during deep winter a bridge

TABLE 1 AVERAGE DAILY TEMPERATURES – JANUARY AND JULY RANGES

Location	Ave. daily temp. (°C)		Latitude/Longitude	
	January range	July range	°N	°E/°W
North America				
Dawson	7.7	13.7	64	139W
Prince George	9.7	14.8	54	122W
Fort Nelson	8.7	13.0	59	122W
Boise	7.8	18.0	43	116W
Edmonton	9.8	12.6	54	113W
Medicine Hat	11.5	15.6	50	110W
Saskatoon	9.9	14.6	52	106W
Regina	10.5	14.8	50	104W
Ennadai Lake	7.1	9.0	61	101W
Bismark	11.7	14.9	47	101W
Winnipeg	9.5	12.7	49	97W
Lincoln	9.9	13.6	41	96W
Omaha	10.5	12.5	41	95W
Gillam	9.6	13.4	56	94W
International Falls	12.6	13.9	49	93W
Duluth	10.3	12.9	47	92W
Pickle Lake	10.9	12.6	51	90W
Quebec	8.8	11.7	47	71W
Fort Mackenzie	11.6	14.0	57	69W
Europe				
Brussels	5.5	10.6	51	4E
Essen	4.7	8.7	51	7E
Lillehammer	6.1	10.5	61	10E
Berlin	5.1	10.0	52	13E
Ceske Budejovice	7.0	11.4	49	14E
Falun	7.5	10.8	61	15E
Zagreb	5.0	10.4	46	16E
Budapest	5.2	11.3	47	19E
Kosice	7.4	12.6	49	21E
Warsaw	5.1	9.5	52	21E
Pulawy	5.2	10.1	51	22E
Vidin	6.9	15.0	44	23E
Suwalki	5.7	9.7	54	23E
Helsinki	5.1	9.1	60	24E
Sliven	6.6	12.3	43	26E
Moscow	6.9	9.9	56	37E
Vologda	8.4	10.7	59	40E
Kotlas	7.2	10.5	61	46E
Kazan	7.5	10.1	56	49E
Adamovka	8.5	13.6	52	60E
Asia				
Sverdlovsk	6.2	8.9	57	61E
Berezouo	4.4	6.6	64	65E
Tashkent	8.9	15.5	41	69E
Alma ata	8.9	11.6	43	77E
Omsk	7.3	10.0	55	73E
Tomsk	6.6	10.6	56	85E
Lhasa[a]	16.7	13.9	30	91E
Ulan Bator	13.3	11.1	48	106E
Tientsin	9.5	9.4	39	117E
Olekminsk	5.0	11.1	60	120E
Mukden	12.7	10.0	42	123E
Seoul	9.4	7.8	38	127E
Vladivostok	7.2	6.1	43	132E
Khabarovsk	6.1	6.7	48	135E
Sapporo	10.0	9.5	43	141E

[a] Very high altitude in Tibet

bearing is unlikely to cycle back to the unstrained state (or may do so but rarely — during a brief mild spell). The data on which *Table 1* was based show that in mid to high latitudes, the deep winter and high summer temperatures do not in general overlap. Furthermore, these data only relate to ambient temperatures: in late spring and summer, solar heating of the bridge structure is likely to lead to temperatures well in excess of the ambient. There is no comparable temperature depressing factor to act on bridge structures in winter. Thus designed bridge movement will be less in winter.

In some mountainous locations, bridges may be located in situations which are in persistent shadow during the winter months. An example of this is bridges located (in the northern hemisphere) on north-facing slopes of deep valleys (such locations are unlikely to be attractive to engineers due to greater snow cover and frost damage, but may be essential for roads or railways to gain height). These locations are likely to be characterised by persistent low temperatures with little possibility for thermal cycling.

At lower latitudes, where the solar influence is less seasonal in nature, diurnal temperature variation is liable to be higher, even when the overall temperature is low. Bridge movement in winter is likely to be greater than that at higher latitudes. Polymers are less likely to crystallise because of the greater movement and the higher ambient temperatures. Clearly, it would be unwise to extrapolate such conditions to higher latitudes where the direct solar contribution is minimal in winter, especially during December/January. The areas liable to experience such persistent low temperatures include Canada, the Northern USA, Scandinavia, most of the Soviet Union, the north of Germany and most of Eastern Europe. Mountainous regions may be subject to continuous low temperatures where the sun remains in shadow for all or much of the year.

CONCLUSIONS

Bridge bearings, especially those made from polychloroprene, may experience temperatures which are low enough to induce crystallisation. It has been suggested that changes in ambient temperature and the consequential bridge movement are sufficient to stop the formation of crystals within the elastomer. Such thermal changes are seasonal in nature: typically the range of temperature experienced in winter is only 70% of the range experienced in summer. Solar heating of bridge structures is a major source of bridge movement, but at high latitudes (greater than 50°) solar heating is reduced in winter, therefore bridge movement is also greatly reduced. Thus thermal cycling as a mechanism for lessening the risk of crystallisation in bridge bearings is less likely to occur at high latitudes in winter.

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