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Review of design temperature for reinforced fill slopes in Hong Kong

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ABSTRACT: Temperature is an important factor to be considered in the design of reinforced fill slopes. Thus it is important to examine local soil temperature data. In this Paper, soil temperatures measured by the Hong Kong Royal Observatory for the past 27 years are examined. The findings and implications of these data on the design of reinforced fill slopes in Hong Kong are discussed.

1 INTRODUCTION

Temperature is an important factor to be considered in the design of reinforced fill structures incorporating polymeric reinforcements. It has an impact on the stress (or creep) rupture and hydrolysis behaviour of polymers and can affect the permissible design load of polymeric reinforcements significantly both in terms of ultimate and serviceability limit states. Jewell & Greenwood (1988) has suggested that the maximum in-service temperature of the structure should be used for design.

On the basis of a review of temperature data published by the Hong Kong Royal Observatory, Geospec 2: Model Specification for Reinforced Fill Structures (GCO, 1989) recommends that a maximum in-service temperature at the facing/soil interface in the range of 30°C to 35°C should be allowed for in the design of a concrete-faced structure (Howells & Pang, 1989). A temperature of 35°C has since been adopted for the design of reinforced fill structures in Hong Kong.

For reinforced fill slopes with a non-structural facing, the tension developed in the reinforcements near the face of the slope is generally small compared to the peak tension developed along the length of the reinforcement. The maximum temperature of 35°C as adopted in the design of reinforced fill walls with a structural facing may not be appropriate for the case of slopes. As part of the Hong Kong Government's initiative to promote the safe and economic use of polymeric reinforcements, the GEO has carried out a further review on the soil temperatures in Hong Kong for the design of reinforced fill slopes.

This Paper examines the soil temperature measurements that have been carried out by the Hong Kong Royal Observatory for the last 27 years. Based on a consideration of temperature and tension distribution, a temperature is proposed for the design of reinforced fill slopes incorporating polymeric reinforcements in Hong Kong.

2 SOIL TEMPERATURE MEASUREMENTS

The Hong Kong Royal Observatory has been collecting soil temperature data at depths of 0.05m, 0.1m, 0.2m, 0.5m, 1.0m, 1.5m and 3m below a flat ground of decomposed granite at its Headquarters since 1968. Similar measurements have also been conducted at the sub-station at King's Park since 1978.

Two soil temperature measurements are recorded daily at 0700hrs and 1900hrs at both sites. The temperatures recorded at 1900hrs are generally higher than those at 0700hrs. The data are published annually in the report "Surface Observations in Hong Kong" (e.g. Royal Observatory Hong Kong, 1993). The following data have been obtained directly from the Royal Observatory at both sites for detailed examination:

(a) daily soil temperatures measured at 1900hrs from 1990 to 1994,

(b) monthly average soil temperatures from 1968 to 1994, and

(c) records of all daily soil temperatures at

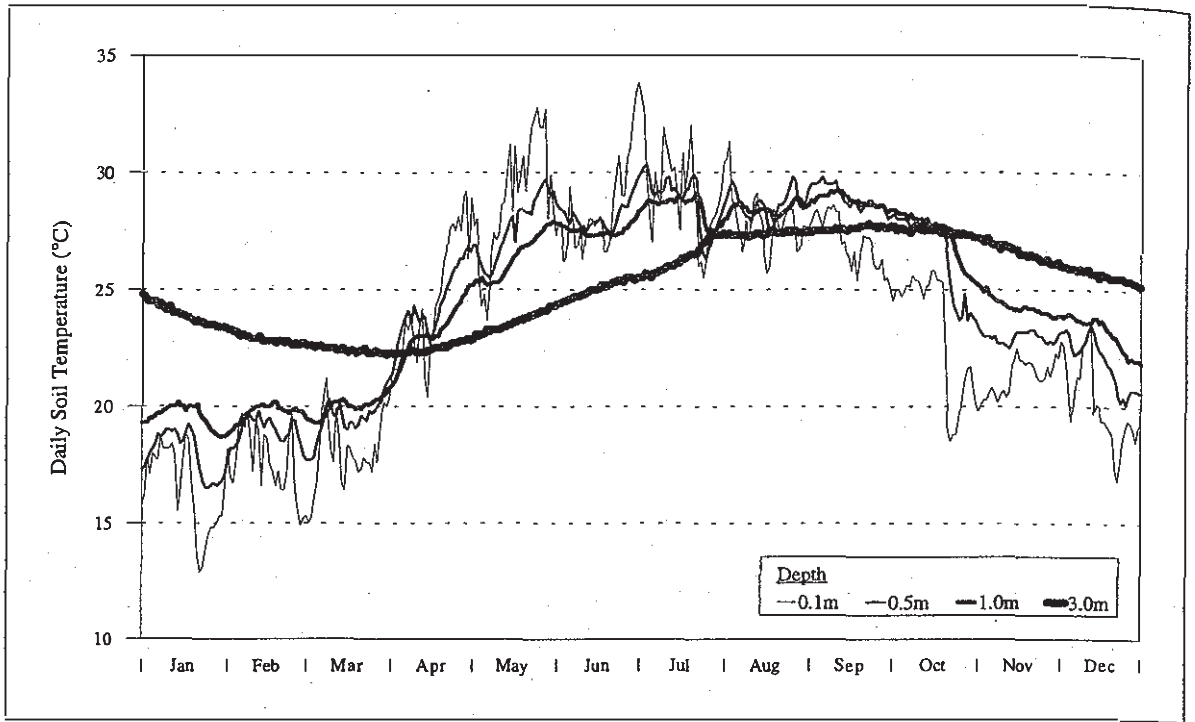

Figure 1 - Daily Soil Temperatures Measured at Selected Depths at the Royal Observatory Headquarters in 1994

1900hrs.

Since late May of 1995, automatic recording of soil temperature has been carried at 15-minute intervals at all depths at the Royal Observatory. However, these data have yet to be published by the Royal Observatory. A review of the data on selected sunny days in July and August, i.e. the hottest days, indicates that the soil temperature recorded at depths greater than 0.5m remains fairly constant throughout the day, with variations less than 0.5°C.

In general, the temperature range recorded using the automatic device is consistent with that of the manual operation. However, the automatic measurement gives a slightly lower daily maximum soil temperature than that previously recorded at 1900hrs over 0.5m. As the automatic measurement of temperature has only been carried out for a short time, it is prudent to use these data only as a reference. The data interpretation given in this Paper are based on the manual temperature readings collected over the last 27 years.

3 DATA INTERPRETATION

The daily soil temperatures measured at 1900hrs at selected depths, viz. 0.1m, 0.5m, 1m and 3m, for the years 1990 to 1994 at the Royal Observatory Headquarters and at King's Park have been scrutinised. A typical plot of the daily soil temperatures over a period of one year is shown in Figure 1. From this Figure, it can be seen that the fluctuation of the recorded daily soil temperatures decreases with depth. The difference between the annual daily maximum and minimum soil temperatures also decreases with depth, viz. 20°C and 5°C at a depth of 0.1m and 3m respectively. In addition, there is a timelag between the cycles of daily soil temperature at different depths, i.e. a timelag of 3 months can be observed between 0.1m and 3m depth. This timelag represents the time required for the soil temperature at depth to reach equilibrium as a result of seasonal changes. The maximum and minimum temperatures occurred in July and January (respectively) for the 0.1m depth, as compared to October and April (respectively) for the 3m depth. Therefore, the temperature at a depth of 3m is higher than that at 0.1m for a period of six months in a year, i.e. from October to April. The maximum soil temperature at 3m depth is approximately 6°C lower than that at 0.1m depth, but the minimum temperature is about 9°C higher. Similar trends can be observed from data in other years.

The monthly average soil temperatures at the Royal Observatory (from 1968 to 1994) and at King's Park (from 1978 to 1994) show consistency throughout the monitoring period and the pattern of annual temperature variation repeats each year. A typical plot of the variation of monthly average soil temperature is shown in Figure 2. The maximum monthly average soil temperature is about 31°C, which occurs between the months of July and September for a short duration.

To assess the frequency of occurrence of a selected soil temperature, the probability of daily soil temperature and monthly average soil temperature equal to or exceeding that selected temperature is calculated. The probability P(X) is taken as the number of readings equal to or exceeding the selected temperature X°C over the total number of readings available. Figures 3 and 4 show the probability curves for 1.0 m depth for the two measurement sites. The temperature measurements obtained from King's Park and the Royal Observatory Headquarters are similar and consistent, and the probabilities yielded from these data are very close. From the curves a mean value of the monthly average soil temperature of approximately 26°C, i.e. the value at P(X)=0.5, is obtained, and a slightly higher mean value of between 27°C and 28°C is obtained for the daily temperature. The probability of soil temperature equal to or exceeding 30°C at 1.0m depth is relatively small, i.e. below 10%. The probability of soil temperature exceeding 31°C is negligible.

4 TEMPERATURE EFFECT ON POLYMERIC REINFORCEMENTS

Two of the common polymers used for polymeric reinforcements are drawn (oriented) high density polyethylene (HDPE) and polyester. The effect of temperature on the mechanical behaviour of these polymeric reinforcements can be remarkably different. Creep and hydrolysis are two of the issues which have to be addressed with due consideration given to temperature.

From a design life of 120 years, Small & Greenwood (1993) have estimated on the basis of available stress-rupture data that the retained strength will be reduced by about 9% (from 32% to 29% of the index strength) for HDPE geogrids, when the design temperature increases from 20°C to 35°C. The creep and stress-rupture behaviour of polyester is not as temperature dependent as HDPE. Greenwood (1995a) has indicated that the increase in (creep) strain for each 10°C increase in temperature is only approximately 0.2% and this represents a difference in loading capacity of 2% of the breaking load of polyester geogrids. For the same design life, Greenwood (1995a) has estimated that the retained strength is approximately 50% to 55% of the breaking load, irrespective of the design temperature. Partial safety factors are required to be applied to the above-mentioned retained strengths

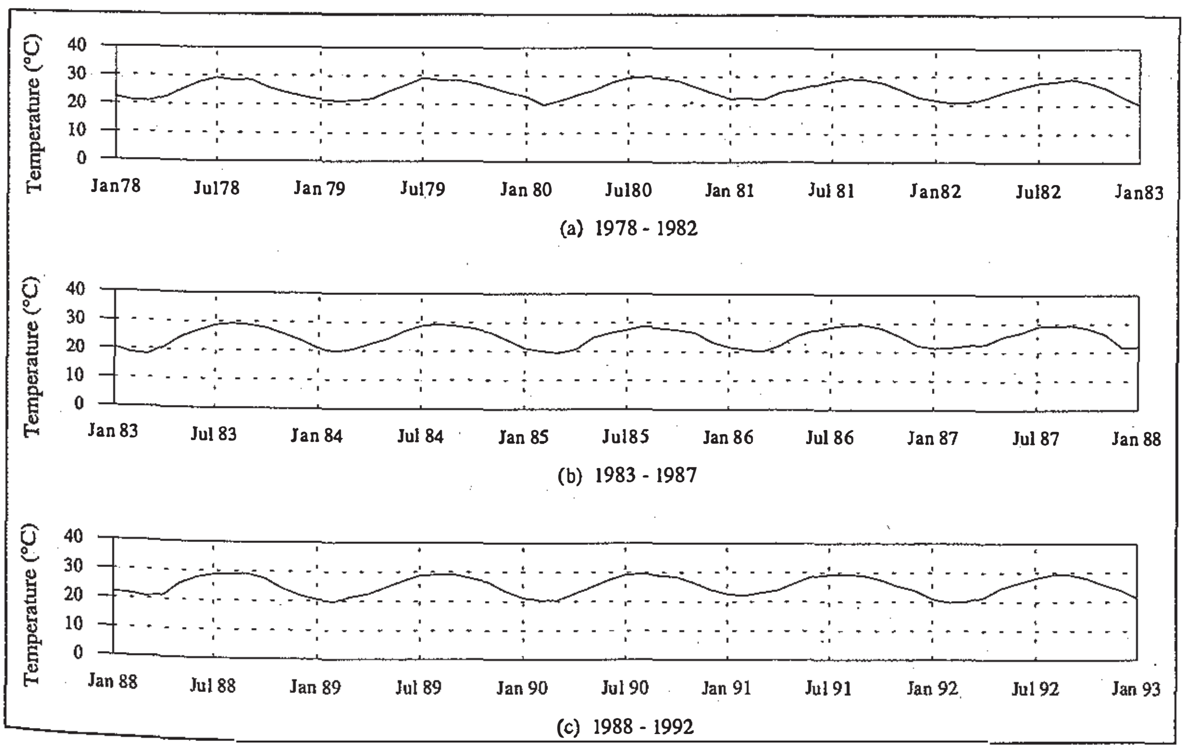

Figure 2 - Variation of Monthly Average Soil Temperature at 1.0m Depth (King's Park)

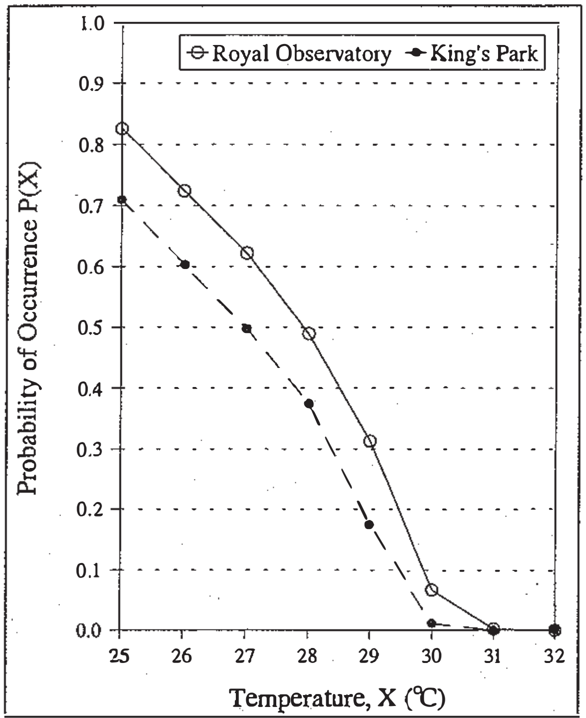

Figure 3 - Probability of Daily Soil Temperature ≥ X at 1.0m Depth

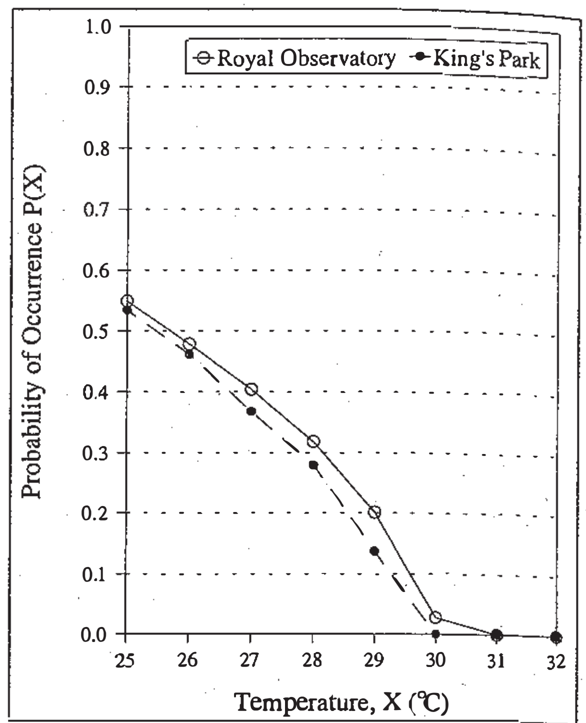

Figure 4 - Probability of Monthly Average Soil Temperature ≥ X at 1.0m Depth

to account for uncertainties associated with the derivation of long-term material strengths.

As for hydrolysis, HDPE is generally not considered to be a problem because of its relatively stable micro-structure. There is no data on hydrolysis of polyester geogrids and research done to date is on the hydrolysis of unprotected yarns only. Such research has indicated that the sensitivity of polyester hydrolysis to temperature is strong. Based on the available results, Greenwood (1995b) has estimated that the retained strength for a design life of 120 years will be reduced by about 20% (from 96% to 76% of the breaking load of the yarns), when the design temperature increases from 20°C to 35°C. In addition, he has suggested that increasing partial safety factors should be applied to the estimated retained strength of polyester geogrids at higher temperatures, to account for the increasing uncertainty in the estimation of the strength loss by extrapolation at such temperatures.

5 DESIGN TEMPERATURE FOR REINFORCED FILL SLOPES

Based on the work of Bolton & Pang (1982), Geospec 2 (GCO, 1989) has recommended that for design purposes the maximum tension for the reinforcing elements should be assumed to lie within a distance of 0.15H from the facing (where H is the height of the structure). For a structure with a concrete facing, the in-service temperature at the facing/soil interface is a maximum and governs the design against tension failure of the reinforcing elements.

There is no information on the tension distribution within a reinforced slope with a non-structural facing at or close to failure. Some strain measurement data are available for full scale structures under working conditions (e.g. Yamanouchi, 1986 and Fannin, 1988). A review of such data indicates that the tension at the face of the slope is small compared to the maximum (peak) tension which occurs more than one metre away from the face. Therefore, to design based on the maximum in-service temperature, which is applicable for only a short period, would be unduly conservative. Greenwood (1995b) has suggested that the continuous (average) in-service temperature may be a more appropriate design condition.

Figures 3 & 4 show that at a depth of 1.0m, the probability of a soil temperature equal to or exceeding 30°C is less than 10%. In view of this low probability of occurrence, the temperature of 30°C can be taken as a conservative estimate for the in-service temperature for the design of reinforced fill slopes in Hong Kong. It should be noted that although the temperature at the slope face may be marginally higher than 30°C, its effect on the strength of the reinforcement is no longer critical as the tension of the reinforcement at the face is very small.

6 CONCLUSIONS

From the available data, the annual average soil temperature in Hong Kong is found to be in the region of 26°C to 28°C. Based on a consideration of temperature and tension distribution, 30°C is proposed here to be used for the design of polymer reinforced fill slopes with a non-structural facing.

For reinforced fill retaining walls with a structural facing, it is important to take into consideration the maximum temperature behind the facing panel as the tension at this location can be significant. Temperature monitoring for three reinforced fill retaining walls in Hong Kong is in progress, and it is intended that the data will be published in due course.

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