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MICRO-PINGOS ON A BRIDGE IN AMSTERDAM

In January and February of this year (1979) a rather unusual phenomenon was manifest on both sidewalks of the draw-bridge connecting the Prins Hendrikkade and the Kattenburgerplein in the city of Amsterdam, the Netherlands (fig. 1). Several more or less spherically and elliptically shaped elevations of the foot-path surface with altitudes varying between a few and about 50 cm, lined up along about the central line of the pathways, appeared to occur there.

On 21th January the basal diameter of the circular specimens ranged between 40 and 260 cm; the long axis of the elliptic ones varied between 220 and 360 cm and the short axis between 120 and 210 cm. In figure 2a a transverse section of the bridge pathway is shown. The steely frame is covered by an about 10 cm thick wood layer consisting of square and rectangular blocks and constructed like an inlaid floor (fig. 2b). This wood layer is overlain by an asphalt cover varying in thickness between 1.5 and 3 cm. The bitumen cover on the summit of the smallest elevations with a diameter of about 40 cm was undamaged, but on somewhat larger specimens it showed a cracking and these cracks were arranged in a sort of radial pattern (pl. 2:I). On still larger, spherical as well as elliptical "domes" the asphalt cracks developed a more rectangular pattern (pl. 1:IV) while the elliptical specimens showed moreover a dominant fissure more or less parallel to their longest axis (pl. 1:II). The largest circular mound showed a collapsed summit (pl. 1:III) revealing an empty internal space.

During later visits it appeared that two specimens on the eastern pathway (pl. 1:II) had been repaired, now by the inlay of exclusively wooden balks which, however, showed again a slight upward curving. New elevations appeared to have been originated a.o. adjacent to the two repaired spots. Moreover, an increase of the basal surfaces and height of the unrepaired micro-pingos was evident. Specimens still closed in January, now showed collapsed summits (pl. 2) while the "crater" of the at the time open specimen was greatly enlarged (pl. 3:II). In addition the crater walls had got a more frayed appearance and were much steeper.

A similarly constructed draw-bridge at a distance of about 100 m (fig. 1), but situated almost normal to the direction of the bridge under consideration, did not show any notable damage during the first visit. On 4th February, however, the sidewalks of this bridge too showed some upheavals of the surface.

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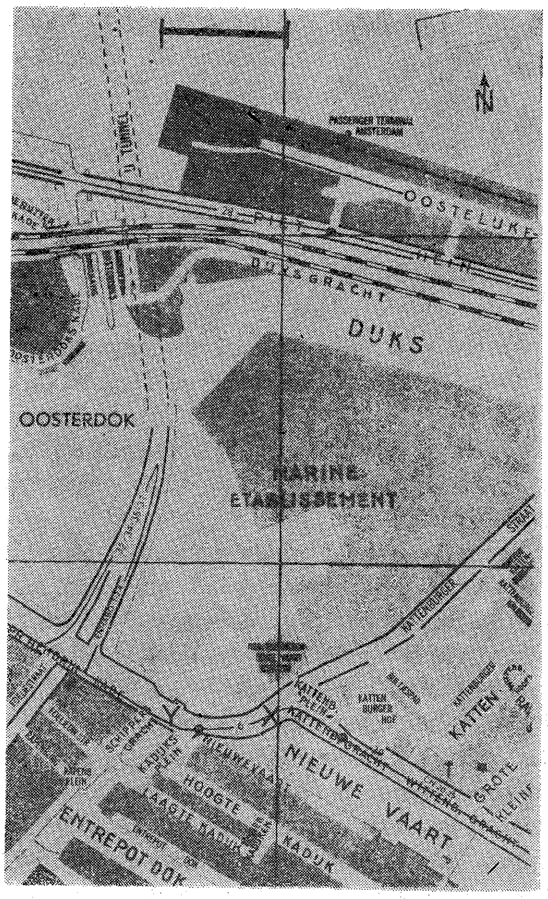
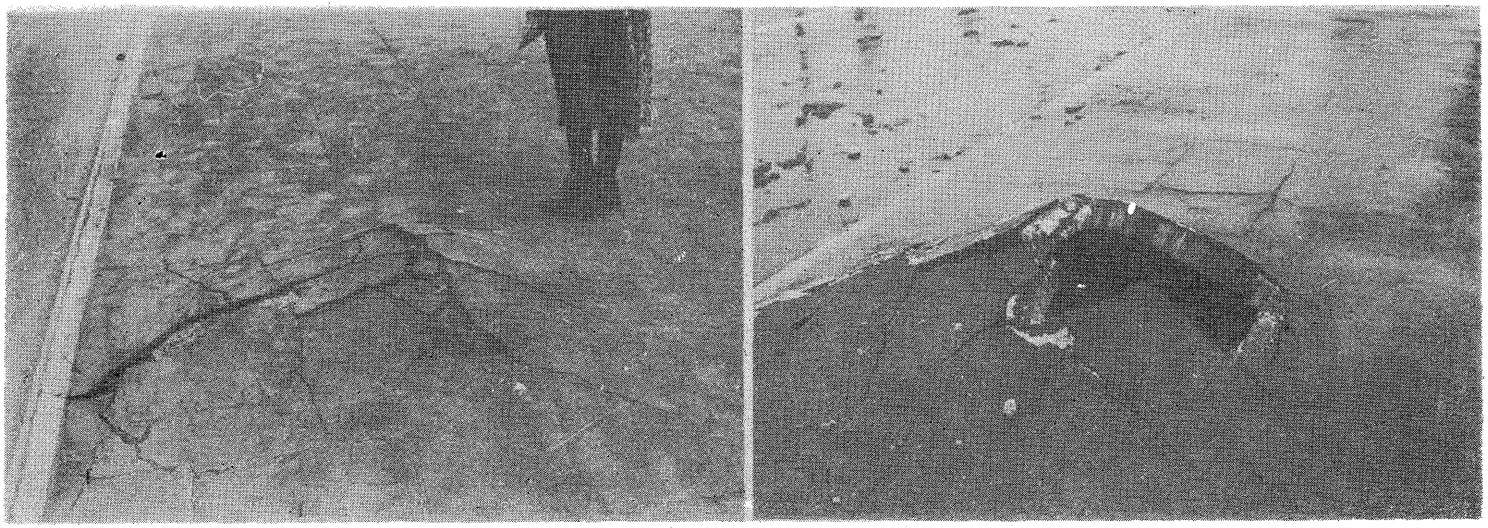


Fig. 1. Location map; X is the draw-bridge concerned and Y the neighbouring one. Bar indicates a distance of 150 m

About the mechanisms causing these micro-pingos only can be hypothesized, but their arrangement in this particular environment, the sequence of known materials in which they originated and the evolution they showed, may be a rather reliable guide in this guesswork. Water supplied by rain or snowmelting must have been present at the steel-wood interface with probably large concentrations (water-lenses) in separate spots along the central line of the foot-paths. Upon freezing especially during the first and third week of January (see fig. 3) this water formed incipient ice-lenses or ice-cores; water from adjacent areas was probably forced to these spots of ice formation and warranted a further growing. However, in contrast to the situation in real permafrost environments, in the succession steel-wood-bitumen-(snow), an *inverse temperature gradient* must have existed during the periods of ice-core formation.

This, because the cooling under the bridge via the steely bottom plate must have been much faster and higher than by the way of the snowy bitumen cover (note the NW—SE direction in figure 1a and the prevailing wind directions in fig. 3). The freezing plane consequently moved mainly upwards in the sequence steel-wood-bitumen-(snow) instead of downwards. The continuous or repeated growth of the

Pl. 1. I — general view of the western pathway on 21th January. Arrows indicate the upheavals of the pavement.
II — a circular and elliptical upheaval on the eastern sidewalk (January 21st)
III — close-up of specimen A (see pl. 3—I) showing a collapsed summit (January 21st)
IV — close-up of specimen D (see pl. 3—I) on 21st January



Pl. 2. I — micro-pingo with a radial crack pattern developed only in the bitumen layer (January 21st)
II — the same specimen on February 4th displaying now a beautiful crater

Pl. 3. I — general view of the western pathway on February 4th. A new micro-pingo originated between the specimens B and C
II — close-up of specimen A (see pl. 1—III) on February 4th
III — close-up of specimens C and D on February 4th
IV — close-up of specimen D on 19th February

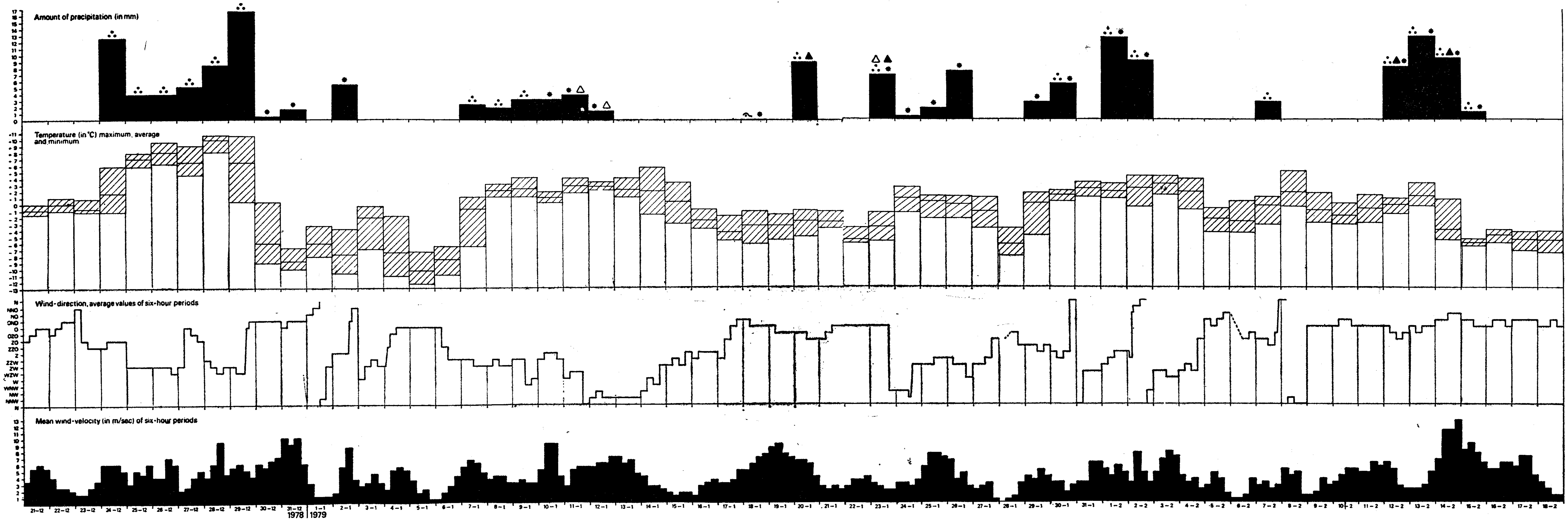


Fig. 3. Some climatological data (December 21 — February 18, 1979)

Precipitation and temperature were recorded at a distance of about 500 m, wind direction and velocity at a distance of about 100 m from the bridge

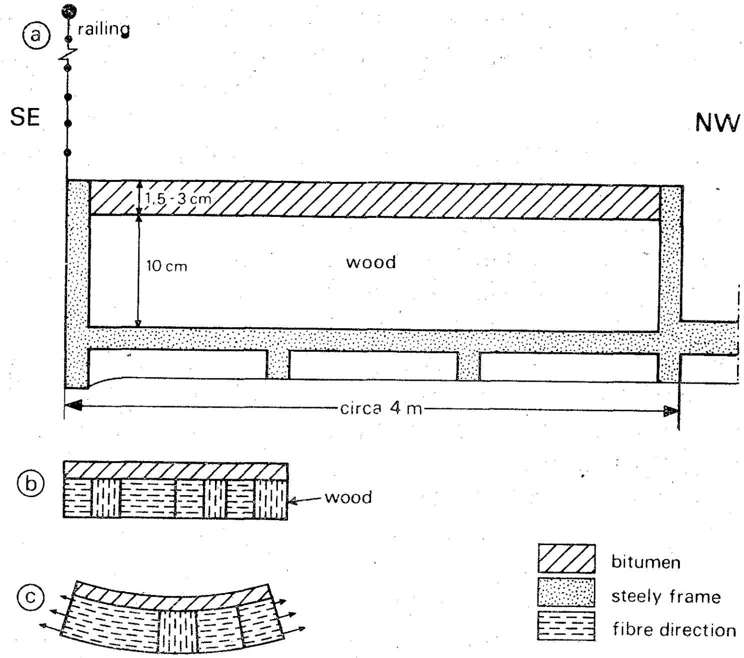


Fig. 2. Schematic cross-section of the foot-path, not to scale

ice-lenses provided locally forces large enough to lift up the "overburden" of wood and asphalt. Later on during the process the uplifting was accompanied by bursting of the bitumen and the inlaid wood layer which allowed during rain and thaw a more intensified supply of water. But it seems reasonable to assume that after the actual opening of the summit cracks the ice-lenses ceased to grow, at least at the very site of the summits. Thus, after the origin of a crater, ice formation did not contribute anymore to a further uplift and steepening of the walls.

However, later visits showed a further growing of the basal surfaces and a height-increase of the crater walls (pl. 3). The enlarging of the basal surfaces might be accounted for by a continuing ice formation at the wedge-chaped steel-wood interface in the lower-slope areas of the elevations. A such-like mechanism might operate even at a complete absence of an ice-core. But the steepening of the crater walls cannot be explained by this and suggests an additional acting mechanism.

Different coefficients of expansion may have played a role in this connection. Consideration of the exact values of wood e.g. (lineair coefficient // wood fibres is 3.10×10^{-6} and $\perp$ wood fibres is $30-70 \times 10^{-6}$) shows that under most favourable conditions (i.e. when the blocks are all situated with their fibres perpendicular to the surface) over a temperature range of 15 degrees the vertical expansion or contraction of the wood layer may amount 0.45 to 1.5×10^{-3} cm while these movements in horizontal direction may vary between 180 and 420×10^{-3} cm. But actually the former two figures are too small and the later ones too large as the orientation of the blocks (and thus of the fibres) is rather randomly (see fig. 2b). However, the effect of this different expansion (and contraction) in the wood layer, which in itself is rather negligible, is enlarged by two circumstances. The first one is that the bitumen is rather firmly attached to the upperside of the wood layer. Thus, forces operating parallel to the wood-bitumen interface are just below this interface counteracted while this obstruction is considerably less just above the steel-wood interface. The development of the rectangular crack pattern in the bitumen which is also visible in the not-elevated portion of the foot paths (see a.o. pl. 2) is probably the result of this. The second circumstance is that also water is involved in the expansion of the wood. This water penetrates into the wood mainly from below as the bitumen attached to the upperside hinders here its coming in. And especially in those wood blocks situated with their fibres normal to the bitumen layer, this penetration occurs very easily. The amount of water and its state of aggregation in the wood has varied repeatedly. But it seems obvious that generally the greatest water content is found in the lowest portion of the wood layer. This and the transition into ice crystals upon freezing provides likewise a greater expansion at the base of the wood blocks. In particular those blocks with their fibres normal to the surface act as real "wedges" and contribute considerably to the magnitude of the expanding forces (fig. 2c).

Summarizing, ice-core upheaval combined with, normal to the surface, an unequal expansion of the wood layer co-operated probably in the production of these micro-pingos. However, after the opening of the summits and the disappearance of the ice-cores, only the later mechanism was responsible for subsequent steepening of the slopes and the development of frayed rims around the crater.